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VOLUME II

EVALUATION OF ADVANCED LIFT CONCEPTS AND FUEL CONSERVATIVE SHORT-HAUL AIRCRAFT

FINAL REPORT

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FOREWORD

The evaluation of Advanced Lift Concepts and Fuel-Conservative Short Haul Aircraft was conducted under extensions to NASA Ames Research Center Contract NAS2-6995. Work was initiated in July 1973 and continued to May 1974 as an outgrowth of the studies reported in the basic contract which extended from May 1972 through May 1973; the earlier work was described in CR 114612 and CR 114613, dated June 1973 and was summarized in CR 2355, dated December 1973.

The results of the study are reported in two volumes for ease of handling. Volume I (NASA CR 137525) covers Introductory material, Evaluation of Requirements and Over-the-Wing/Internally Blown Flap Vehicles. Volume II (NASA CR 137526) covers Augmentor Wing and Mechanical Flap Vehicles, other lift concepts, Evaluation of Aircraft Configurations, Economics, and Conclusions and Recommendations.

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SYMBOLS AND ABBREVIATIONS

AR	airplane aspect ratio or nozzle aspect ratio, b/h
AW	augmenter wing
b	span
BLC	boundary layer control
BPR	bypass ratio, engine secondary airflow/engine primary airflow
C_D	drag coefficient
C_L	lift coefficient
C_P	pressure coefficient
C_R	roll moment coefficient
C_T	thrust coefficient
C_X	axial force coefficient
C	blowing moment coefficient
c	chord
¢/ASSM	cents/available seat statute mile
CTOL	conventional takeoff and landing
D	diameter
dB	decibel
DOC	direct operating cost
DOC-1	DOC at 11.5¢/gallon of fuel
DOC-2	DOC at 23¢/gallon of fuel
DOC-3	DOC at 46¢/gallon of fuel
DOC-4	DOC at 1.15¢/gallon of fuel
EBF	externally blown flap
EPNdB	equivalent perceived noise decibel
F	engine thrust

f	frequency (Hertz)
FAR	Federal Aviation Requirements
FPR	fan pressure ratio
g	gravitational constant
H	nozzle height
Hz	Hertz, unit of frequency
IBF	internally blown flap
LE	leading edge
M	Mach number or Meter
m	airflow or meter
MF	mechanical flap
NPR	nozzle pressure ratio
OASPL	overall sound pressure level
OPR	overall pressure ratio of engine
OTW	over-the-wing
OTW/IBF	over-the-wing/internally blown flap hybrid
OWE	operating weight empty
PNdB	unit of perceived noise level
PNL	perceived noise level
q	dynamic pressure
R	coanda radius
RGW	ramp gross weight
R_N	Reynolds number
ROI	return on investment
R/STOL	reduced/short takeoff and landing

SFC	specific fuel consumption
SLS	sea level static
SPL	sound pressure level
STOL	short takeoff and landing
T	temperature or airplane net thrust
t	wing thickness
T/O	takeoff power setting
TOFL	takeoff field length
TOGW	takeoff gross weight
T/W	airplane thrust/weight ratio
T/S	airplane thrust/wing area ratio
V	velocity
W	weight or airplane weight
α	angle of attack
γ	flight path angle
Δ	increment of
η	power setting or fraction of wing span
λ	taper ratio

SUMMARY

In 1972 and early 1973, Lockheed conducted for NASA Ames Research Center a "Study of Quiet Turbofan STOL Aircraft for Short Haul Transportation" (Ref. 1,2). This study concluded that quiet, short-field aircraft can be economically viable, provide benefits to short-haul transportation, and also to long-haul transportation through relief of airport congestion. From a comprehensive array of lift concepts, cruise speeds, and field lengths, it was concluded that the most promising concepts were the 910 m. (3,000 ft.) field length Over-the-Wing/Internally Blown Flap Hybrid (OTW/IBF) and the 1220 m. (4,000 ft.) field length Mechanical Flap (MF) concept, both with cruise speeds of 0.8M.

Additional depth of analysis was needed to confirm the potential of these concepts and to evaluate the performance and economics of a twin-engine augmentor wing airplane. The present study covers two phases:

- o Investigation of the critical design aspects of the OTW/IBF hybrid, augmentor wing, and mechanical flap aircraft for 910 m. (3,000 ft.) field length with parametric extension to other field lengths.
- o Evaluation of the fuel savings achievable by the application of advanced lift concepts to short-haul aircraft and determination of the effect of different field lengths, cruise requirements, and noise levels on fuel consumption and airplane economics at higher fuel prices. This approach to the present study is summarized in Figure 0.1.

All the design comparisons were made with 148 passenger aircraft. The baseline aircraft for design refinement had a single-aisle, 6-abreast fuselage; a 5-abreast fuselage was used in the fuel-conservative configurations because it is slightly lower in weight and wetted area. Engines used in the designs were those defined in the pre-hardware phases of the Quiet Clean STOL Experimental Engine program, with the addition of a near-term bypass 6 engine currently under development. An advanced airfoil was used in all of the

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- REFINE DESIGN OF SHORT-HAUL AIRCRAFT -- M 0.8, 9140m. (30,000 FT.)

FIELD LENGTH	610m. (2000 FT.)	910m. (3000 FT.)	1070m. (3500 FT.)	1220m. (4000 FT.)
OVER THE WING/INTERNALLY BLOWN FLAP	∘	⊛	∘—∘ PARAMETRIC DESIGN	
MECHANICAL FLAP		⊛	∘	⊛
AUGMENTOR WING	∘	⊛—PRELIMINARY DESIGN		

- REOPTIMIZE ABOVE AIRCRAFT (WING AR, CRUISE SPEED AND ALTITUDE) FOR MINIMUM FUEL AND HIGHER FUEL COSTS
  REEXAMINE EXTERNALLY BLOWN FLAP
  ADD DEFLECTED SLIPSTREAM WITH TURBOPROP ENGINES
  EXTEND MECHANICAL FLAP ANALYSES TO COVER 1830m. AND 2440m. (6000 AND 8000 FT.)
  EVALUATE ENGINES WITH FPR 1.25, 1.35, 1.47

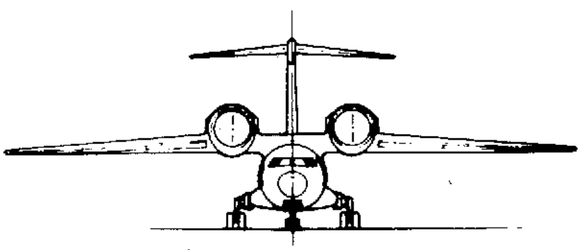
- DETERMINE FUEL AND DOC PENALTY FOR POTENTIAL NOISE CRITERIA:
  - 95 EPNdB AT 150m. (500 FT.) SIDELINE
  - PART 36 MINUS 5, 10, 15 EPNdB
  - SPERRY BOX LEVEL OF 80 EPNdB
  - 90 EPNdB FOOTPRINT AREA LIMITED TO 2.59, 1.39, 0.78 km^2 (1.0, 0.5, 0.3 SQ. MI.)
  - 90 EPNdB FOOTPRINT LENGTH LIMITED TO 6.5, 3.7, 1.9, 1.2 km (3.5, 2.0, 1.0 N. MI., 4000 FT.)

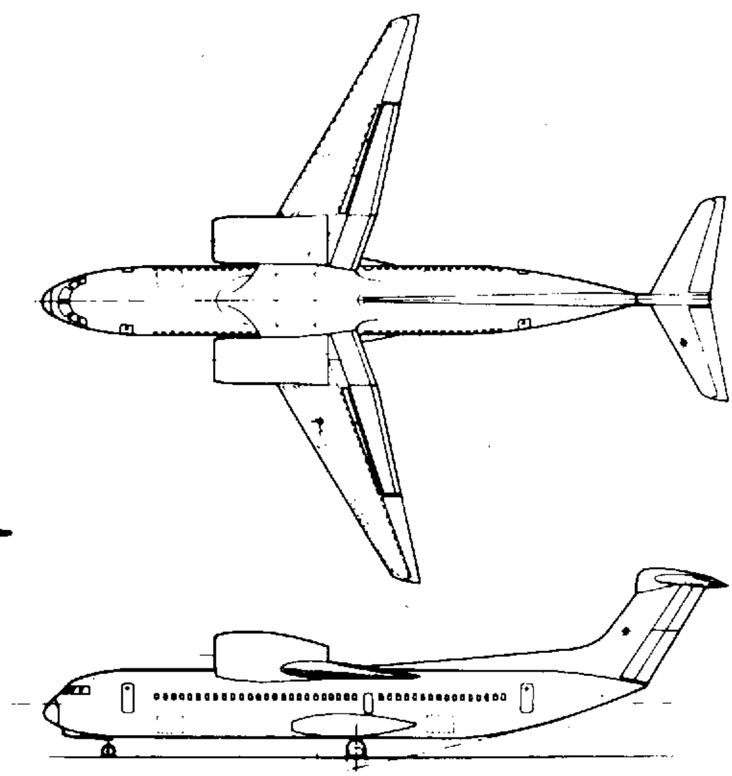
FIGURE 0.1: STUDY APPROACH

148 PASSENGERS

0.8 MACH

910 M (3000 FT) FIELD LENGTH





SPAN = 35.56 M (116.66')

LENGTH = 42.57 M (139.66')

HEIGHT = 11.78 M (38.66')

FIGURE 0.2: 910 M (3000 FT) OTW-IBF VEHICLE

configurations, providing a greater wing thickness for a given drag rise, sweep angle, and design cruise speed.

In all cases, emphasis was given to designs meeting noise levels equivalent to 95-100 EPNdB at 153 m. (500 ft.) sideline. The range of fan pressure ratios for engines used in the designs was chosen to cover a range of noise levels from slightly below 95 to considerably higher than 100 EPNdB at this sideline location. Effects of this variation are summarized later. The concepts were compared at approximately the same low noise level by utilizing the engine fan pressure ratios and noise treatment listed in Table 0.1.

The following discussion is organized to cover, first, the design refinement of the hybrid OTW/IBF concept and changes associated with minimizing fuel consumption or minimizing operating cost at higher fuel prices. Next, the augmentor wing and mechanical flap concepts are covered. The other lift concepts are examined more briefly from the standpoint of fuel conservation. The concepts are then compared, noise aspects are summarized, and conclusions and recommendations are listed.

Hybrid OTW/IBF Aircraft

The hybrid OTW/IBF airplane is characterized by location of the engines over the wing and use of Coanda attachment for thrust vectoring, combined with ducting of a small proportion of the fan air to trailing edge flaps for low speed lift augmentation. Cross-ducting of the fan air in the IBF system makes it possible to achieve lift symmetry in a two, three, or four engine configuration. The baseline airplane resulting from design refinement, and optimized for minimum direct operating cost at 1972 fuel prices, is shown in Figure 0.2. Detailed analysis covered the following areas:

- o Nacelle inlet, exhaust and thrust reverser design; Coanda jet deflection.
- o Mass flow split, ducting, and flap configuration.
- o Limits on engine size related to wing area, expressed as thrust/wing area (T/S) limit.
- o Aerodynamic performance and comparison of data from Lockheed and other wind tunnel tests.
- o Weights of flap, ducting, wing box and other components.

TABLE 0.1 ENGINE SELECTION FOR CONCEPT COMPARISON AT EQUIVALENT NOISE LEVELS

Lift Concept	Engine FPR	Acoustic Treatment
Hybrid OTW/IBF	1.35	Nacelle Wall only
Augmentor Wing	3.0 - 3.2	High Mach Inlet; Exhaust Duct Wall; Flap Cavity
Mechanical Flap	1.35	Nacelle Wall only
Externally Blown Flap	1.25	Nacelle Wall only
Over-the-Wing	1.35	Nacelle Wall only
Boundary Layer Control/ Vectored Thrust	1.3	Nacelle Wall only
Internally Blown Flap/ Vectored Thrust	1.3	Nacelle Wall only
Deflected Slipstream	(Turboprop)	Nacelle Wall and Low Tip-Speed Prop

The engine is positioned so it can be lowered vertically forward of the wing front beam. The nacelle design, coordinated with the available aerodynamic test data, incorporates separate fan and primary exhaust ducts. The length and geometry of the aft fan duct cause significant cruise penalties. This area is considered to have most potential for improvement of the performance potential of the OTW/IBF concept, but requires experimental data which are now lacking.

A subcontract with Detroit Diesel Allison Division of General Motors covered studies of fan-air bleed systems, potential emergency ratings for engine loss conditions, surge margin requirements, and generation of additional noise data.

Characteristics of aircraft resulting from design refinement are shown in Table 0.II for design field lengths of 610, 914, and 1070 meters (2,000, 3,000, and 3,500 ft.). Although these aircraft were optimized for fuel prices of 1972 levels (identified as DOC-1) the table shows the effect of multiples of 2, 4, and 10 times that fuel price (identified as DOC-2, DOC-4, and DOC-10). Direct operating costs are based on 3,000 hours per year utilization of the aircraft with 2780 Km (1,500 n.m.) range capability instead of the 2,500 hours per year utilization which is predicted for aircraft with 926 Km (500 n.m.) range limits.

Modification of design for fuel conservation and for minimum DOC at higher fuel prices involved reexamination of cruise speed and altitude, as well as airplane configuration. Because of the large number of cases to be considered, the aircraft were designed for 926 Km (500 n.m.) range only, with associated utilization of 2,500 hours per year; the comparisons would be valid and could be applied to aircraft with extended range and CTOL takeoff. Figure 0.3 shows mission fuel, DOC-1 and DOC-2 plotted against design cruise Mach number for airplanes optimized for minimum mission fuel and alternately for minimum DOC-1 or DOC-2. The figure shows that the vehicle designed for minimum DOC-1 would have 2 engines and a cruise speed of 0.8 M, as represented in Figure 0.2. Its mission fuel usage would be 5900 Kg (13,000 lb.) and its DOC-1 would be 1.62¢/ASSM. Figure 0.3 also shows that at 0.8 M the alternate 4-engined vehicle incurs an increase in DOC-1 (1.5%), but mission fuel is reduced 16%. When an increase in fuel price is considered, this

TABLE 0.11 OTW/IBF BASELINE AIRCRAFT CHARACTERISTICS

148 Passengers
M 0.8 at 9140 m. (30,000 ft.)

926 Km Range with Design Field Length
2780 Km Range with CTOL Takeoff

Design Field Length - M (Ft.)		< 610 (<2,000)	< 914 (<3,000)	< 914 (< 3,000)	< 1,070 (< 3,500)
Engine Fan Pressure Ratio		1.35	1.35	1.47	1.35
No. of Engines		4	2	2	2
Ramp Gross Weight - Kg		73,190	75,987	78,849	73,279
(Lb.)		(161,360)	(167,520)	(173,830)	(161,550)
Operating Weight - Kg		44,489	45,670	46,267	43,768
Lb		(98,080)	(100,680)	(102,000)	(96,490)
Wing Loading - Kg/sq. mi.		467	449	459	471
(T.O. 926 Km Mission) Lb/sq. ft.		95.6	92.0	94.0	96.5
Wing Aspect Ratio		10	7.7	7.7	7.7
Wing Thickness/Chord		0.127	0.131	0.130	0.130
Thrust to Weight Ratio		0.43	0.49	0.47	0.46
Thrust/Engine - KN		74.3	175.5	172.0	160.3
Lb.		16,760	39,450	38,660	36,040
Cruise Thrust Setting		1.0	0.93	0.79	0.98
926 Km (500 n.m.)	DOC-1 - ¢/ASSM	1.74	1.61	1.59	1.59
	DOC-2 - ¢/ASSM	2.02	1.92	1.94	1.89
	DOC-4 - ¢/ASSM	2.58	2.52	2.63	2.47
	DOC-10 - ¢/ASSM	4.25	4.35	4.80	4.24
	Mission Fuel - Kg	6,128	6,687	7,607	6,476
	Lb	13,510	14,742	16,770	14,276
2780 Km (1500 n.m.)	DOC-2	1.51	1.44	1.47	1.40
	Mission Fuel - Kg	13,145	14,554	16,565	13,872
	Lb	28,980	32,086	36,518	30,582
Complete Aircraft Price - $M		9.622	8.831	8.696	8.578
Engine Price - $M		3.128	2.110	1.902	2.045

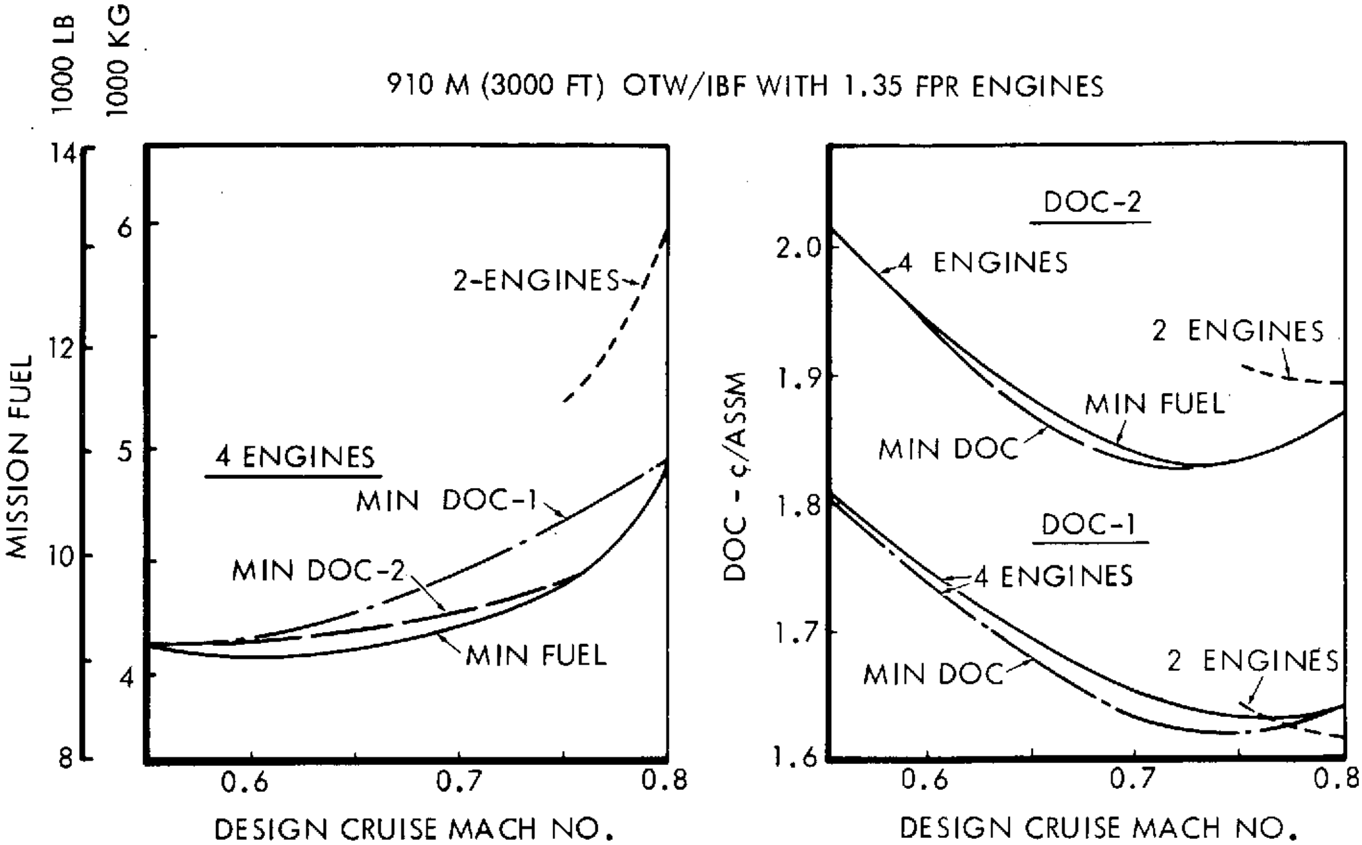


FIGURE 0.3: EFFECT OF DESIGN CRUISE SPEED

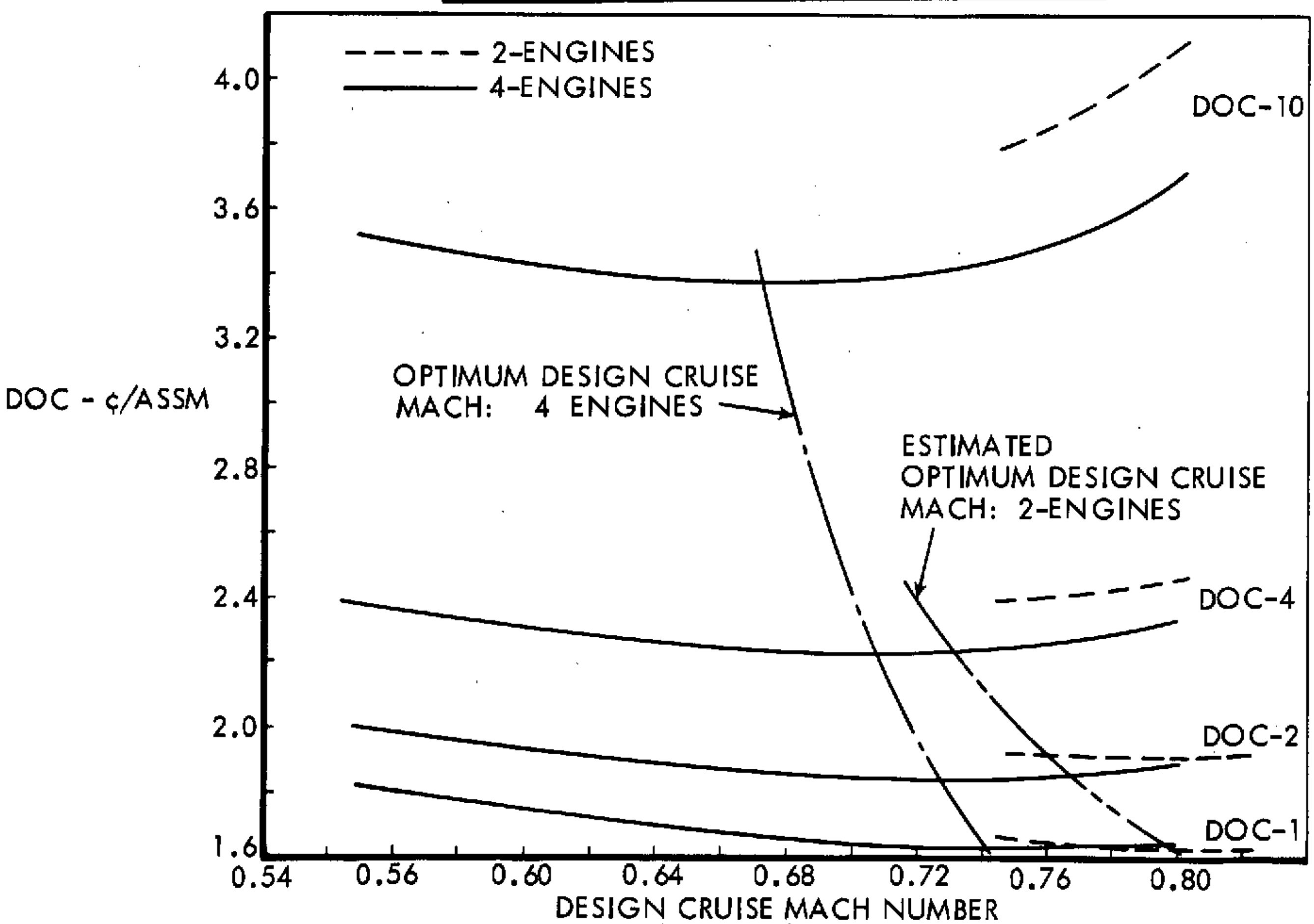


FIGURE 0.4: 1.35 FPR OTW/IBF: EFFECT OF FUEL PRICE ON OPTIMUM DESIGN CRUISE SPEED 910M (3000 FT.) FIELD LENGTH

airplane has a DOC-2 1.3% lower than the 2-engined configuration.

If the airplane had been optimized for minimum mission fuel, the figure shows a 4-engined, 0.6 M design requires only 4080 Kg (9,000 lb.), a saving of 31% relative to the original DOC-1 design. However, this saving is associated with a 8 % increase in DOC-1 to 1.75¢/ASSM, while at DOC-2 the penalty is 2.6%. While this configuration provides an excellent reduction in mission fuel, it is doubtful that it would be accepted because of the increase in DOC and the large reduction in cruise speed.

If the airplane is optimized for DOC at the increased fuel price, a 4-engined, 0.73 M configuration provides a DOC-2, 4% lower than the original optimized design and requires 27% less fuel for the mission. Thus, it can be seen that by optimizing for minimum DOC at the increased fuel price, fuel savings close to the design optimized for minimum fuel can be achieved while still minimizing operating costs.

Figure 0.4 presents DOC at various fuel price levels plotted against design cruise Mach number for 2- and 4-engined designs which use optimum aspect ratios and cruise altitudes. The buckets in the curves determine the design cruise Mach number for minimum DOC at each fuel price, which when connected together form the lines of optimized cruise speed. Note that optimum cruise speed reduces with increase in fuel price as would be expected.

The effect of engine fan pressure ratio on DOC at various fuel price levels is illustrated in Figure 0.5 for airplanes having optimum cruise speed, altitude and aspect ratio. These data were developed for the OTW/IBF, 3,000 ft. concept designed with each of the three engine cycles. It can be seen that DOC-1 is achieved with 1.47 FPR at 0.8 M while minimum DOC-10 is achieved with 1.32 FPR and 0.68 M. An excellent choice for fuel prices ranging from DOC-2 through DOC-10 is 1.35 FPR since it provides DOC's close to minimum in all cases.

The optimum aspect ratio varied for different fuel prices; airplanes optimized for minimum fuel require aspect ratios of the order of 14, while airplanes optimized for DOC-2 require aspect ratios of the order of 10-12, compared to 7-8 for minimum DOC-1.

Table 0.III summarizes the design characteristics of the OTW/IBF configurations

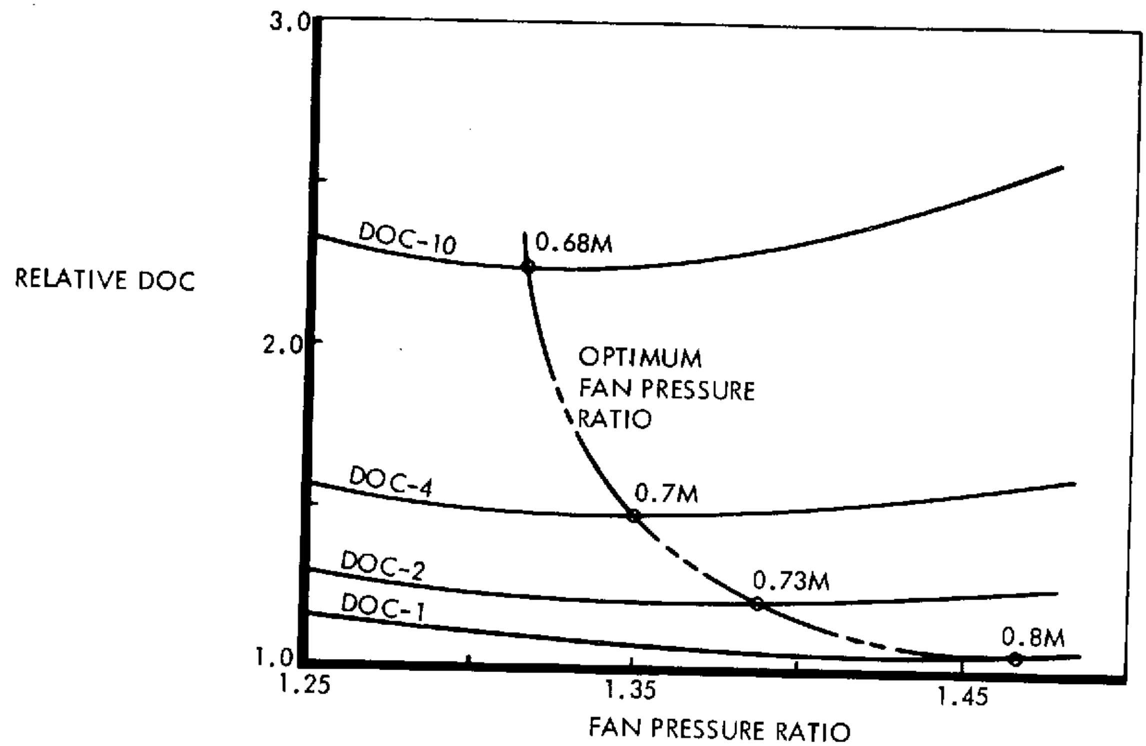


FIGURE 0.5: EFFECT OF FUEL PRICE ON OPTIMUM FAN PRESSURE RATIO - OTW/IBF CONCEPT, 910 M (3000 FT) F.L.

	1.32 FPR V.P. DOC-1 REF. 2	OPTIMIZED FOR DOC-1	OPTIMIZED FOR DOC-2	OPTIMIZED FOR DOC-4	OPTIMIZED FOR DOC-10	OPTIMIZED FOR MIN. FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.70	0.60
NO. OF ENGINES	2	2	4	4	4	4
OWE - KG	44,570	43,450	36,510	35,290	35,290	34,870
(LB)	(98,250)	(95,790)	(80,490)	(77,800)	(77,800)	(76,880)
GROSS WEIGHT - KG	66,840	65,550	56,450	54,670	54,670	53,910
(LB)	(147,350)	(144,520)	(124,440)	(120,520)	(120,540)	(118,860)
RATED THRUST - KN	163.7	167.5	55.3	48.0	48.0	44.1
(LB)	(36,810)	(37,660)	(12,440)	(10,790)	(10,790)	(9,910)
MISSION FUEL - KG	6,330	6,030	4,400	4,210	4,210	$\boxed{4,070}$
(LB)	(13,960)	(13,300)	(9,700)	(9,290)	(9,290)	(8,975)
AR	7.0	7.73	12	14	14	14
*DOC-1 -- ¢/ASSM.	$\boxed{1.797}$	$\boxed{1.616}$	1.634	1.646	1.646	1.747
DOC-2 -- ¢/ASSM.	-	1.889	$\boxed{1.831}$	1.837	1.837	1.937
DOC-4 -- ¢/ASSM.	-	2.437	2.246	$\boxed{2.221}$	2.221	2.307
DOC-10 - ¢/ASSM.	-	4.08	3.441	3.373	$\boxed{3.373}$	3.422
$W/S_{T.O.}$ - KG/SQ. M.	455	449	554	530	530	457
(LB/SQ.FT)	(93.2)	(92.0)	(113.5)	(108.5)	(108.5)	(93.5)
90 EPNdB T.O. AREA	1.30	1.19	1.53	1.45	1.45	1.40
SQ. KM (SQ. MI)	(0.5)	(0.46)	(0.59)	(0.56)	(0.56)	(0.54)

$\underbrace{\text{DOC-4} \quad \text{DOC-10}}_{\text{IDENTICAL AIRPLANE}}$

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2
1500 IN PRESENT PHASE

TABLE 0.III: FUEL CONSERVATIVE AIRPLANE CHARACTERISTICS 1.35 FPR, OTW/IBF, 910 M (3000 FT) F.L.

designed for 148 passengers, 926 km (500 n.m.) range, 910 m (3,000 ft.) field length and optimized for minimum DOC-1, 2, 4, and 10 and for minimum fuel. For reference, the study airplane reported in NASA CR 1146 12 (Ref. 2) is also tabulated in the first column. The higher DOC-1 for this airplane, compared to the present study airplane shown in column 2, is due primarily to the higher-priced variable-pitch fan (pressure ration 1.32) engine used in the reference 2 design. The data in column 2 reflect the refinement achieved in the present study in the airplane designed for minimum DOC-1. Also shown in this column are the DOC-2, DOC-4, and DOC-10 values for that same airplane. The third column shows that for minimum DOC-2, the design cruise speed is decreased to Mach 0.75, the optimum number of engines increased from 2 to 4, and the gross weight decreased significantly. DOC's at different fuel prices are also shown for this airplane, which is illustrated in Figure 0.6. Aircraft with minimum DOC-4 and DOC-10 were identical in the discrete designs examined; design speed and gross weight were further reduced. The last column shows that the aircraft consuming least fuel has a design speed of Mach 0.60. Because of the lower productivity associated with this speed, and higher crew and amortization costs per mile, the DOC is higher at all fuel prices evaluated -- up to 10 times 1972 fuel prices.

Augmentor Wing (AW) Aircraft

The augmentor wing concept utilizes a jet flap in which air from engines with high fan pressure ratios is ejected from the trailing edge. Excellent lift augmentation for terminal area performance is achieved and thrust is augmented through ejector action. Although the DOC was indicated to be higher than that of the hybrid OTW/IBF or the MF configurations in the reference 2 studies, it was not determined whether a two-engine AW configuration would change this conclusion. Accordingly, comparison of two and four engine configurations was undertaken in the present study, and the effect of higher fuel prices on design optimization was investigated.

Detailed studies were conducted on duct configuration, wing geometry optimization, flow split between leading and trailing edge, and T/S limitations. The resulting characteristics are summaried in Table 0.IV for airplanes optimized for minimum DOC-1, DOC-2, and fuel. Comparison of 2- and 4-engine airplanes is shown under the DOC-1

148 PASSENGERS

0.75 MACH

910 M (3000 FT) FIELD LENGTH

OPTIMIZED FOR DOC-2

SPAN = 34.75 M (114')
LENGTH = 46.3 M (152')
HEIGHT = 11.8 M (38.71)

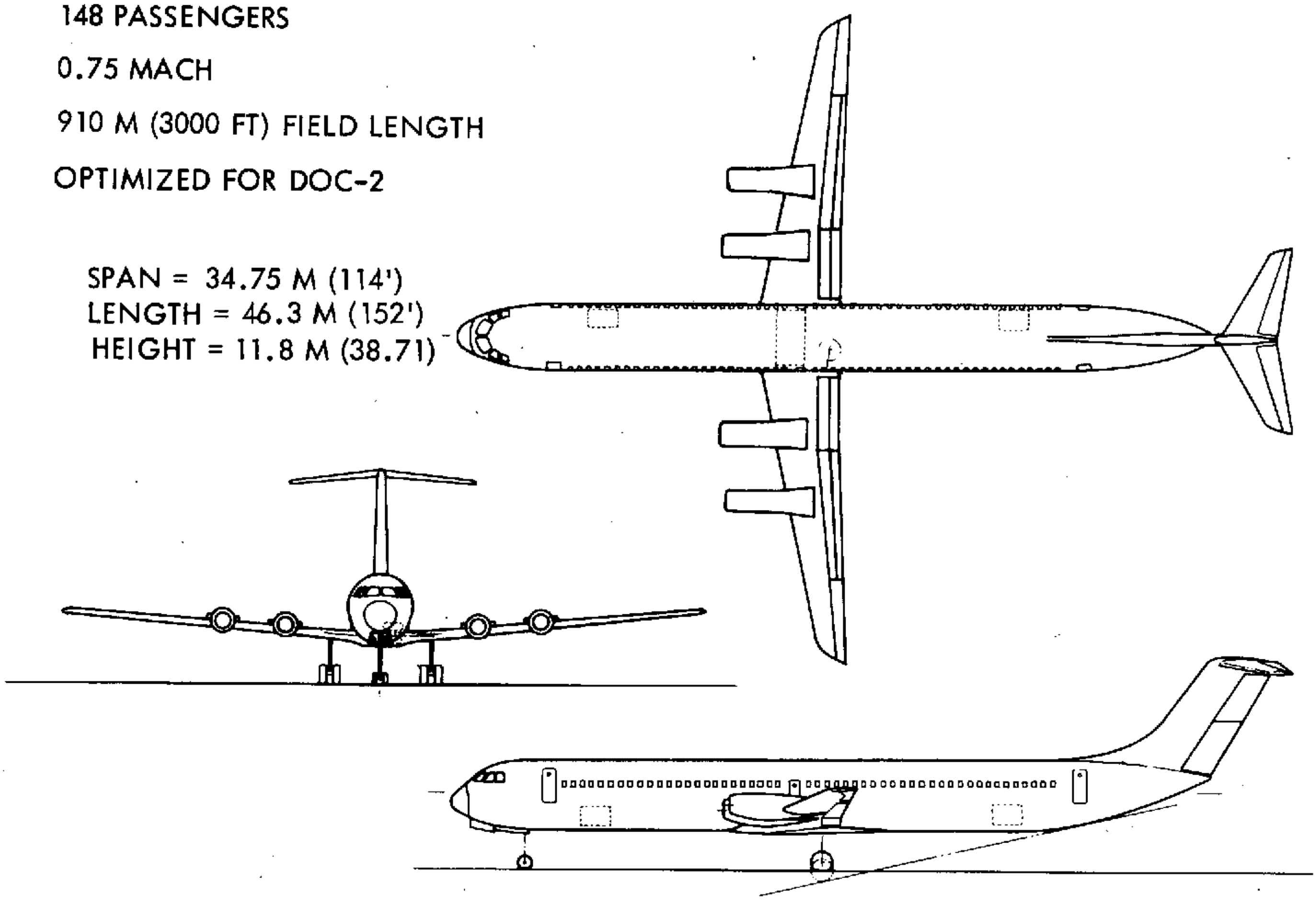


FIGURE 0.6: 910 M (3000 FT) F.L. OTW/IBF VEHICLE OPTIMIZED FOR DOC-2

column; in this concept the 4-engine configuration is superior because of the following factors:

- o The wing loading for the 2-engine airplane is restricted to a lower value because duct volume requirements necessitate a larger wing.
- o Lower flap deflections associated with second-segment climb provide lower augmentation ratios for the 2-engine airplane defined in Table 0.IV. This factor might be overcome by designing to fully deploy the augmentor at very small flap deflections. The associated reduction in thrust requirement would improve DOC-1 to approximately 1.97¢/ASSM. and the ramp gross weight would be reduced to 82,000 kg (180,000 lb.).
- o Engine pricing for the 2-engine configuration was based on a production quantity of 750 engines; if the pricing were based on 1500 engines (300 aircraft plus 25 percent spares in a 4-engine design), the DOC would be reduced further to 1.89¢/ASSM. However, it must be noted that the FPR 3.0 engine cannot be used for other powered lift or CTOL applications; the original engine pricing based on a fixed number of STOL aircraft sets is more realistic.

The 4-engine airplane optimized for DOC-1 is illustrated in Figure 0.7. The configuration features engines placed on the upper surface of the wing in order to maximize available volume for ducts by locating engines as far as possible inboard; the upper surface location permits a more inboard location for the same degree of interference drag. The wing planform has a constant chord section extending to the outboard engine for the purpose of maximizing at a given wing area the chord (and duct volume) at this location.

The columns headed DOC-2 in Table 0.IV reflect the characteristics of aircraft with further design refinement for reducing fuel consumption and minimizing DOC-2. The first airplane uses four engines with 3.2 FPR and improved SFC in a configuration similar to that shown in Figure 0.7. Reduction in mission fuel is significant compared to the

910 M (3000 FT) FIELD LENGTH

OPTIMIZED FOR	REF. 2 DOC-1	DOC-1		DOC-2		MIN. FUEL
NO. OF ENGINES	4	4	2	4	2 + 2	2 + 2
FPR	3.0	3.0	3.0	3.2	1.35 (3.0)	1.35 (3.0)
MACH NO.	0.8	0.8	0.8	0.75	0.75	0.75
CRUISE ALT. - M (FT)	9,140 (30,000)	9,140 (30,000)	9,140 (30,000)	7,620 (30,000)	9,140 (30,000)	9,140 (30,000)
AR	6.5	6.0	5.0	8.5	10.0	14.0
SWEEP - DEG.	30	20	20	10	10	10
$W/S_{T.O.}$ - KG/SQ.M (LB/SQ. FT)	473 (96.9)	512 (105.0)	369 (75.5)	491 (100.5)	547 (112.0)	503 (103.0)
$T/W_{T.O.}$	0.324	.347	.444	.305	.29 (.41)	.28 (.39)
RGW - KG (LB)	72,350 (159,503)	69,900 (154,100)	92,910 (204,830)	63,460 (139,900)	65,030 (143,370	69,070 (152,280)
OWE - KG (LB)	47,530 (104,779)	45,260 (99,790)	63,570 (140,150)	40,890 (90,150)	44,810 (98,790)	49,490 (109,100)
MISSION FUEL - KG (LB)	8,408 (18,537)	8,256 (18,200)	11,706 (25,806)	6,559 (14,460)	7,049 (12,540)	5,583 (12,309)
DOC-1 - ¢/ASSM	1.90	1.88	2.164	-	-	-
DOC-2 - ¢/ASSM	-	-	-	2.11	2.015	2.079
90 EPNdB T.O. AREA - SQ. K (SQ. MI.)	- -	1.30 (0.5)	- -	< 1.30 (< 0.5)	~1.30 (~0.5)	- -

TABLE 0.IV AW - AIRPLANE CHARACTERISTICS

148 PAX

0.8 M

910 M (3000 FT) FIELD LENGTH

SPAN = 28.9 M (94.7')

LENGTH = 42.4 M (139')

HEIGHT = 11.7 M (38.5')

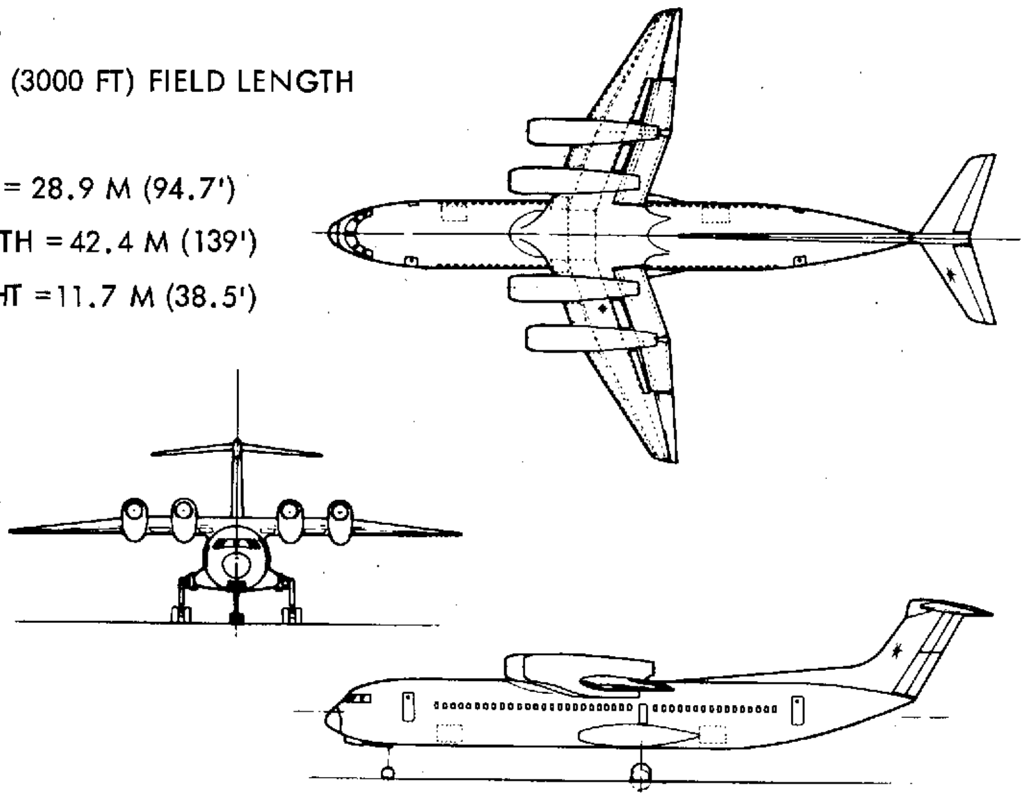
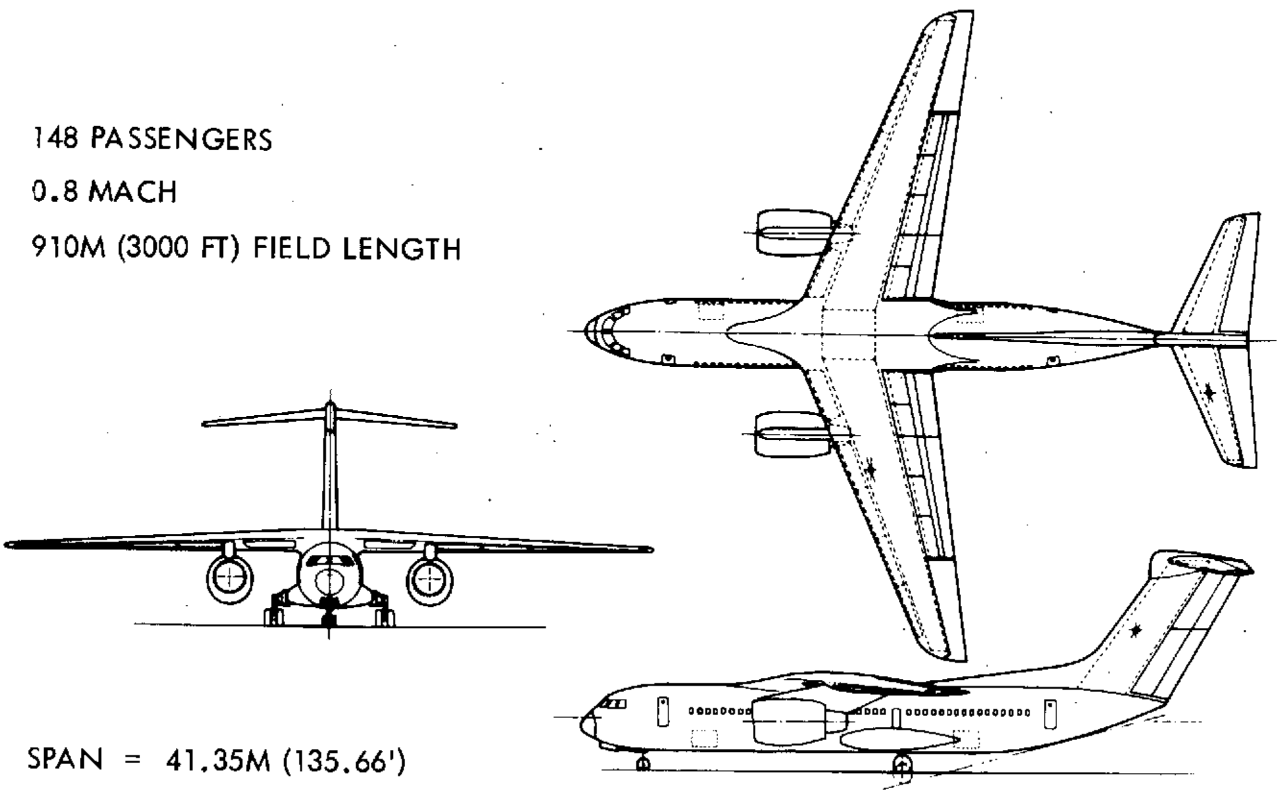


FIGURE 0.7: 910 M (3000 FT) AW VEHICLE - DOC-1

148 PASSENGERS

0.8 MACH

910M (3000 FT) FIELD LENGTH



SPAN = 41.35M (135.66')

LENGTH = 43.18M (141.66')

HEIGHT = 14.22M (46.66')

FIGURE 0.8: MF - GENERAL ARRANGEMENT, FPR 1.35

DOC-1 airplane. Further reduction in fuel and DOC is attainable by an arrangement which uses two FPR 1.35 cruise engines combined with two FPR 3.0 load compressors for low speed high-lift operations. This is labeled 2 + 2 in Table 0.IV. It is recognized that two sets of unlike engines would be regarded with disfavor by airline operators; although this arrangement gives the best fuel performance possible in an augmentor wing concept, it is higher in DOC and fuel consumption than other concepts.

Mechanical Flap Aircraft

Aircraft for 910 m. (3,000 ft.) field performance were defined using a high-performance double-slotted Fowler flap; maximum lift coefficient was 3.3. Landing approach speed of 182.2 Km/hr. (99 kts.) was the critical factor in establishing the wing loading at 287 Kg/m.^{2} (58.8 psf). The basic arrangement, shown in Figure 0.8, has a 6 abreast fuselage with high wing, tee tail and pylon-mounted nacelles.

Considerable improvement in installed engine performance (compared to previous studies) was achieved in the present study by utilizing nacelles designed for best aerodynamic performance with acoustic treatment installed on wall surfaces only. Preliminary Design weight and analyses with allowances for fatigue, gust loads, and flutter were made, along with control and ride qualities investigations which indicated conceptually that augmentation systems could achieve satisfactory ride qualities.

Characteristics of aircraft resulting from the design refinement are shown in Table 0.V, including the extension of the designs to 1070 m (3500 ft.) and 1220 m (4000 ft.) field lengths. These aircraft were optimized for minimum DOC at 1972 fuel prices; the DOC values shown for different fuel prices are based on taking advantage of the 2780 Km range capability to increase the utilization of the aircraft to 3000 hours per year.

The designs were modified for fuel conservation and for minimum DOC at increased fuel prices by evaluating factors such as cruise speed and altitude, wing aspect ratio and sweep, and number of engines. The effect of cruise speed on mission fuel and DOC-2 is shown in Figure 0.9. (Airplane design range was 926 Km (500 n.m.) and utilization was 2500 hours per year for DOC calculations). The fuel penalty is high for higher cruise speed for the low wing loading airplane with 910 m (3000 ft.) field performance.

148 PASSENGERS
MO.8 AT 9140 M (30000 Ft.) ALT.

TWO ENGINES, 20 DEG. SWEEP

926 KM (500 N.M.) RANGE WITH DESIGN FIELD LENGTH
2780 KM (1500 N.M.) RANGE WITH CTOL TAKEOFF

DESIGN FIELD LENGTH - M	914	1,070	1,220	1,220
-(FT)	(3,000)	(3,500)	(4,000)	(4,000)
FAN PRESSURE RATIO/TYPE	1.35 F/P	1.35 F/P	1.35 F/P	1.47 F/P
WING ASPECT RATIO	7	8	10	10
RAMP GROSS WT. - KG	77,963	69,289	65,781	68,095
-(LB)	(171,877)	(152,753)	(145,020)	(150,121)
OPERATING WEIGHT - KG	47,724	41,633	39,529	40,255
- (LB)	(105,212	(91,784)	(87,144)	(88,745)
WING LOADING T.O. - KG/SQM	287	345	403	403
926 KM MISSION (LB/SQ. FT.)	(58.8)	(70.6)	(82.5)	(82.5)
T/W 926 KM MISSION	0.450	0.416	0.386	0.354
RATED THRUST/ENGINE - KN	168.6	139.7	123.8	114.9
-(LB.)	37,898	31,401	27,826	25,830
CRUISE THRUST SETTING	1.000	1.000	1.000	0.866
T/C	14.16	13.69	13.11	13.07
926 KM DOC-1 - ¢/ASSM	1.62	1.50	1.44	1.40
DOC-2-¢/ASSM	1.93	1.85	1.67	1.65
DOC-4-¢/ASSM	2.53	2.37	2.13	2.17
DOC-10-¢/ASSM	4.33	3.80	3.52	3.72
MISSION FUEL - KG	6593	5625	5088	5676
-(LB.)	(14,536)	(12,400)	(11,218)	(12,514)
2780 KM DOC-2-¢/ASSM	1.43	1.30	1.23	1.25
MISSION FUEL - KG	14,471	12,207	10,964	12,359
-(LB.)	(31,902)	(26,911)	(24,170)	(27,246)
COMPLETE A/C PRICE - $M	8.629	7.976	7.678	7.573
ENGINE PRICE - $M	2.081	1.948	1.868	1.652

TABLE 0.V: MF - BASELINE AIRPLANE CHARACTERISTICS

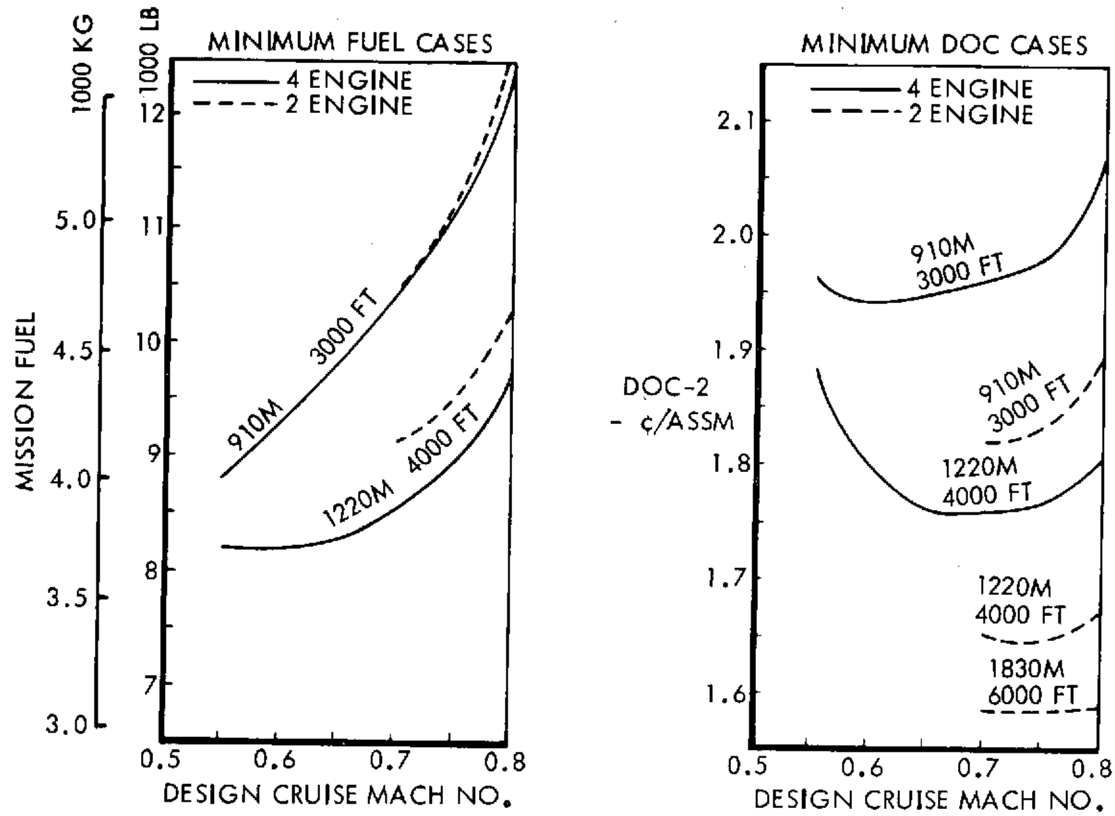


FIGURE 0.9: EFFECT OF DESIGN CRUISE SPEED - MF WITH 1.35 FPR ENGINES

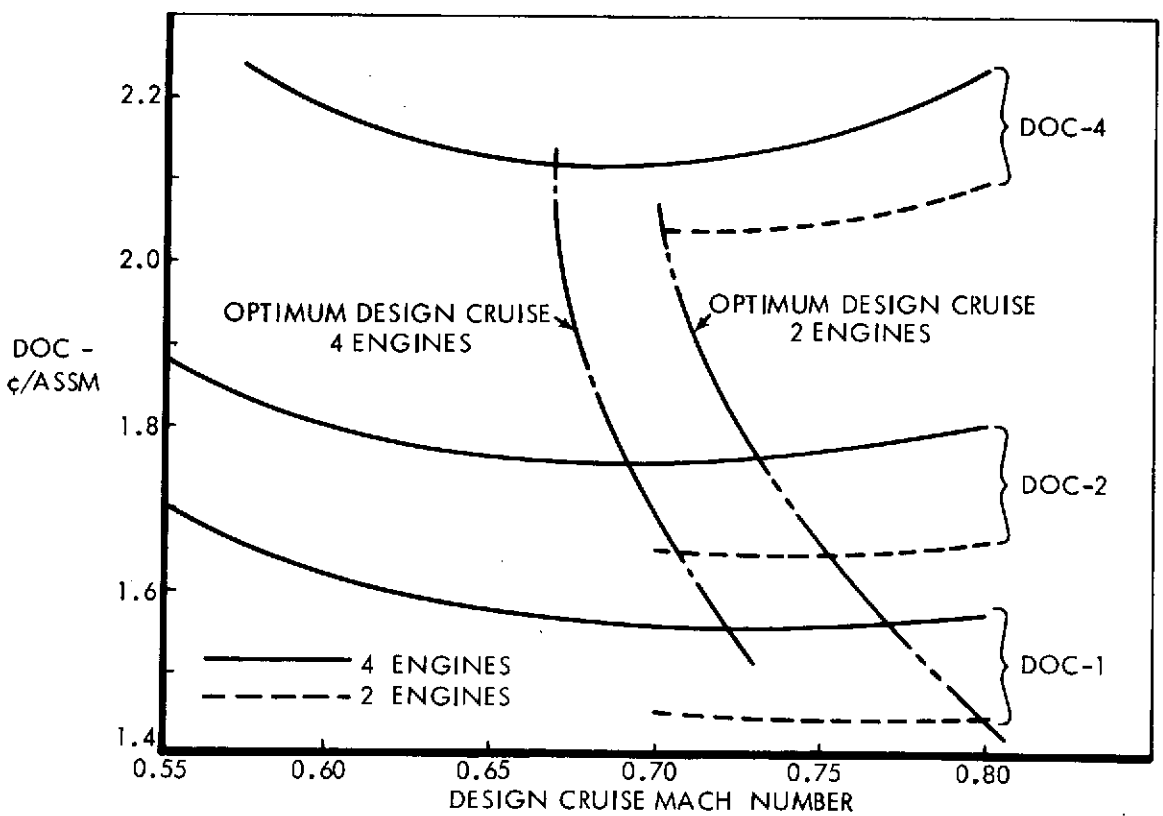


FIGURE 0.10: EFFECT OF FUEL PRICE ON OPTIMUM DESIGN CRUISE SPEED: 1220 M (4000 FT) FIELD LENGTH MF

Effect of other fuel prices on design speed for minimum DOC is reflected in Figure 0.10 for the 1220 m. (4000 ft.) MF airplane. Although the four-engine airplanes require less fuel, the two-engine airplanes provide minimum DOC at fuel prices up to those represented by DOC-4.

Tables 0.VI and 0.VII summarize the characteristics of MF configurations designed for 910 m. (3000 ft.) and 1220 m. (4000 ft.) with 148 passengers and 926 Km (500 n.m.) range. The study airplanes defined in reference 2 are also tabulated. A significant improvement is shown in the present study, primarily due to the improved installed engine performance achieved by elimination of acoustic splitters in the nacelles. The airplane designed for 1220 m. (4000 ft.) field performance and optimized for minimum DOC-2 is shown in Figure 0.11.

Other Concepts Evaluated for Fuel Conservation

The study completed in 1973, "Study of Quiet Turbofan STOL Aircraft for Short Haul Transportation" (reference 2) included evaluation of externally blown flap, over the wing, boundary layer control, and internally blown flap lift concepts. These have been reexamined in the present study in the light of fuel conservation and increased fuel prices.

The externally blown flap airplane with 1.25 FPR engines has a design cruise speed of 0.65 M for minimum DOC-2. It is a four-engine configuration with aspect ratio 10. Fuel consumption and DOC-2 are shown in Figure 0.12, along with other lift concepts. Although its fuel is acceptably low, the DOC-2 is high, principally because of the low cruise speed and low fan pressure ratio engine which is required for comparable noise levels.

The over-the-wing concept is closely comparable to the four-engine hybrid OTW/IBF except, of course, the IBF component is deleted and the flap would be modified for Coanda turning aft of the nacelle, and slotted elsewhere. At higher fuel prices, the economic advantage of two engines in the hybrid OTW/IBF is lost so the four-engine OTW must be regarded as a competitive concept.

Boundary layer control and internally blown flap concepts both require vectoring of the fan air to achieve the required approach glide slopes. Under-wing installations with

	REF. 2 DOC-1	OPTIMIZED FOR DOC-1		DOC-2	DOC-4	DOC-10	MIN FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.70	0.60	0.55
NO. OF ENGINES	2	2	2	2	2	4	4
OWE - KG	52,590	46,870	41,760	40,020	40,020	38,270	35,290
(LB)	(115,940)	(103,330)	(92,060)	(88,230)	(88,230)	(84,380)	(77,800)
GROSS WEIGHT - KG	76,610	69,000	62,690	60,210	60,210	57,700	54,200
(LB)	(168,890)	(152,110)	(138,200)	(132,740)	(132,740)	(127,210)	(119,480)
RATED THRUST - KN	195.5	151.6	125.3	118.4	118.4	43.4	38.5
(LB)	(43,950)	(34,070)	(28,160)	26,610)	(26,610)	(9,760)	(8,660)
MISSION FUEL - KG	7,550	6,110	5,440	4,870	4,870	4,200	$\boxed{3,980}$
(LB)	(16,640)	(13,460)	(12,000)	(10,730)	(10,730)	(9,250)	(8,770)
AR	7.0	7.0	7.0	7-10	7-10	10	14
*DOC-1 -- ¢/ASSM.	$\boxed{1.931}$	$\boxed{1.632}$	$\boxed{1.582}$	1.597	1.597	1.75	1.828
DOC-2 -- ¢/ASSM.		1.912	1.832	$\boxed{1.818}$	1.818	1.94	2.010
DOC-4 -- ¢/ASSM.		2.472	2.328	2.262	$\boxed{2.262}$	2.32	2.376
DOC-10 -- ¢/ASSM.		4.152	3.760	3.589	3.589	$\boxed{3.46}$	3.472
W/S T.O. - KG/SQ.M.	302	287	287	287	287	287	287
(LB/SQ.FT)	(61.8)	(58.8)	(58.8)	(58.8)	(58.8)	(58.8)	(58.8)
90 EPNdB T.O. AREA	1.04	1.48	1.40	1.37	1.37	1.09	1.06
SQ. KM (SQ. MI)	(0.4)	(0.57)	(0.54)	(0.53)	(0.53)	(0.42)	(0.41)

IDENTICAL AIRPLANE

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2 1500 IN PRESENT PHASE

TABLE 0.VI: AIRPLANE CHARACTERISTICS
1.35 FPR, MF 910 M (3000 FT) F.L.

	REF. 2 DOC-1	OPTIMIZED FOR DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.65	0.60
NO. OF ENGINES	2	2	2	2	4	4
OWE - KG	40,510	39,140	36,770	35,790	33,800	33,920
(LB)	(89,300)	(86,280)	(81,060)	(78,900)	(74,520)	(74,770)
GROSS WEIGHT - KG	62,120	59,400	56,460	55,340	52,590	52,530
(LB)	(136,950)	(130,950)	(124,480)	(122,000)	(115,950)	(115,800)
RATED THRUST - KN	150.3	114.3	111.0	104.8	40.9	38.0
(LB)	(33,800)	(25,690)	(24,950)	(23,560)	(9,190)	(8,550)
MISSION FUEL - KG	5,865	4,717	4,382	4,218	3,801	$\boxed{3,715}$
(LB)	(12,930)	(10,400)	(9,660)	(9,300)	(8,380)	(8,190)
AR	7.0	10.0	10.0	10.0	14.0	14
*DOC-1 -- ¢/ASSM.	$\boxed{1.681}$	$\boxed{1.446}$	1.45	1.466	1.626	1.70
DOC-2 -- ¢/ASSM.		1.67	$\boxed{1.648}$	1.659	1.798	1.87
DOC-4 -- ¢/ASSM.		2.10	2.05	$\boxed{2.044}$	2.142	2.21
DOC-10 -- ¢/ASSM.		3.408	3.25	3.20	$\boxed{3.174}$	3.23
W/S T.O. - KG/SQ.M.	455	391	393	379	403	361
(LB/SQ.FT)	(93.1)	(80.0)	(80.5)	(77.6)	(82.5)	(74.0)
90 EPNdB T.O. AREA	0.97	1.42	1.37	1.32	1.088	N/A
SQ. KM (SQ. MI)	(0.375)	(0.55)	(0.53)	(0.51)	(0.42)	

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2
1500 IN PRESENT PHASE

TABLE 0.VII: AIRPLANE CHARACTERISTICS
1.35 FPR, MF, 1220 M (4000 FT) F.L.

148 PASSENGERS

0.75 MACH

1220 M. (4000 FT) FIELD LENGTH

OPTIMIZED FOR DOC-2

SPAN = 37.8 M (124')
LENGTH = 46.3 M (152')
HEIGHT = 11.8 M (38.7')

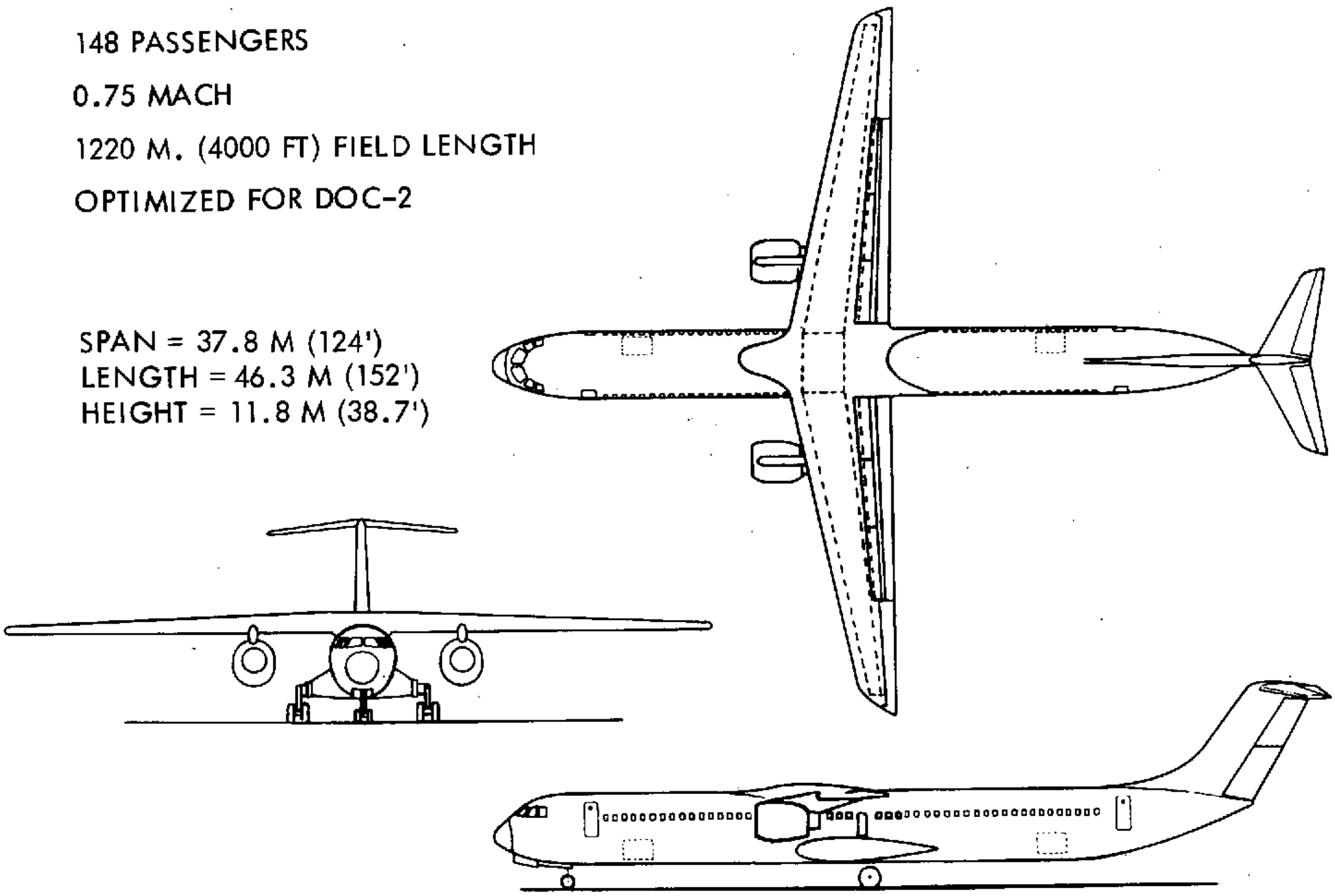


FIGURE 0.11: 1220 M (4000 FT) MF VEHICLE - DOC 2

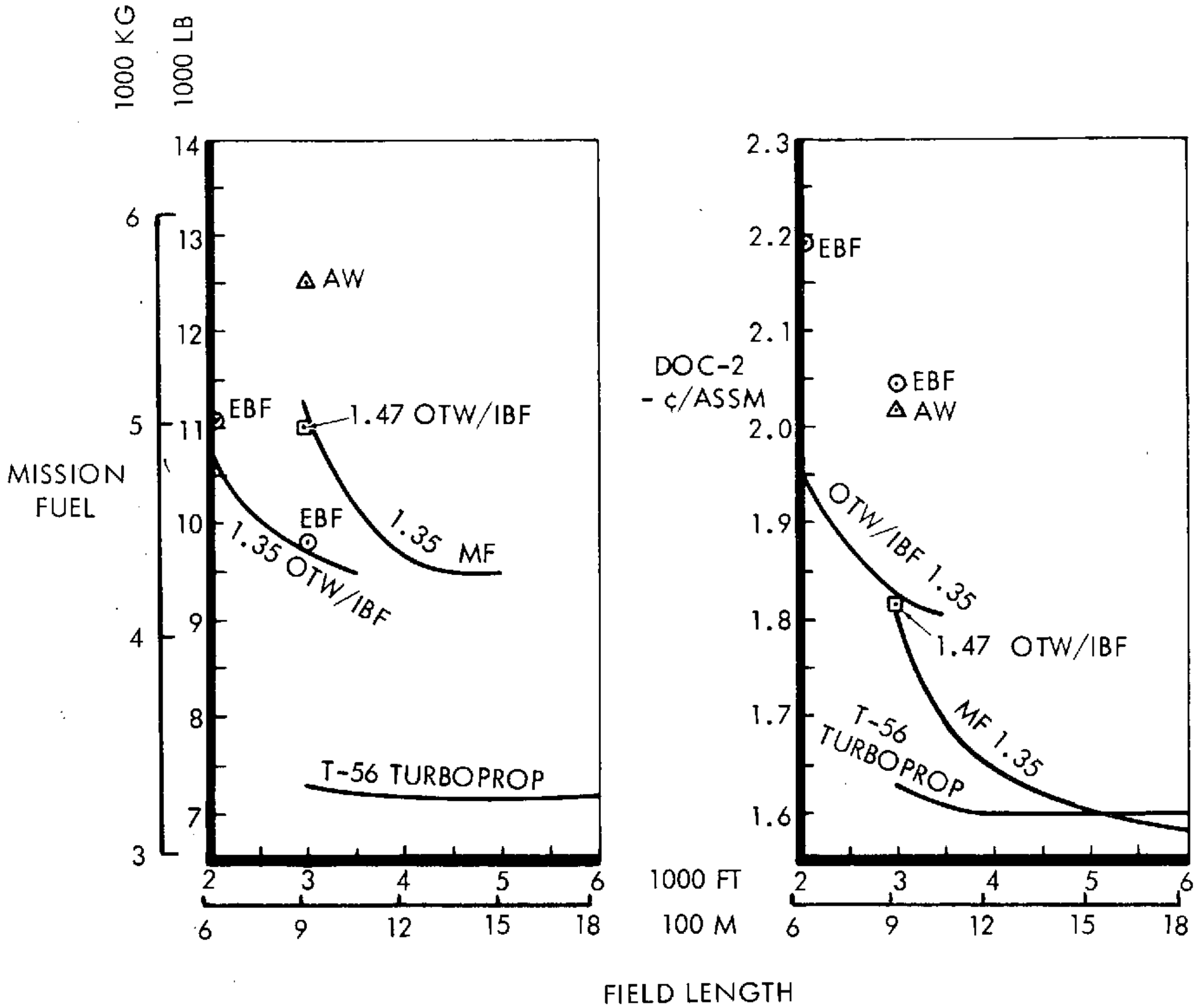


FIGURE 0.12: COMPARISON OF CONCEPTS - MINIMUM DOC-2 CASES

Pegasus-type nozzles showed inferior cruise performance, DOC and fuel consumption compared to other concepts.

Aircraft were designed with rubberized T-56 turboprop engines and with conventional and low-tip-speed propellers. Stall speed margins were based on power-on conditions, providing allowable wing loadings higher than those based on power-off as required by FAR Part 25. The quiet propeller aircraft had better fuel consumption and DOC due to the higher low-speed thrust permitting higher wing loadings for a given field performance. Cruise speeds were Mach 0.5 to Mach 0.6. Fuel and DOC-2 are shown as a function of field length in Figure 0.12. Characteristics of aircraft designed for 910 m. (3000 ft.) field performance with different fuel price levels are shown in Table 0.VIII.

If the T-56 turboprop deflected slipstream concept were acceptable from considerations of passenger appeal and cruise speed, it would be the best choice for field lengths up to 1525 m. (5000 ft.). It is suggested that this application is most suitable in the low to medium density short haul market, particularly at stage lengths below 700 Km (380 n.m.). It is not likely to compete successfully for passengers in competition with higher-speed fan-powered aircraft in high-density routes such as Chicago-New York. Since the present study is primarily concerned with the latter high-density arena, the turboprop deflected slipstream aircraft have been included only as a reference in the comparisons that follow.

Evaluation of Aircraft Configurations

Noise analyses and tradeoffs were conducted to determine the economic penalty associated with the various potential noise requirements, such as FAR 36, less than FAR 36, 95 EPNdB at the 500 ft. sideline, 80 EPNdB at Sperry Box, and footprint area and length for various noise level contours. The analyses were arranged to indicate the effect of concepts, fan pressure ratio, field length and fuel price variations on the various noise level measuring parameters.

Table 0.IX summarizes the effect of noise constraints on airplane configuration, DOC-2, and fuel consumption with no restriction on the performance factors. With cruise speed and block time unrestricted, the two-engine mechanical flap aircraft with 1830 m. (6000 ft.) field length and FPR 1.35 engines satisfies many noise restrictions with no

	OPTIMIZED FOR				
	DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.60	0.55	0.55	0.50	0.50
NO. OF ENGINES	4	4	4	4	4
OWE - KG	35,690	34,805	34,805	34,360	34,360
(LB)	(78,680)	(76,730)	(76,730)	(75,750)	(75,750)
GROSS WEIGHT - KG	54,440	53,170	53,170	52,720	52,720
(LB)	(120,028)	(117,223)	(117,223)	(116,232)	(116,232)
MISSION FUEL - KG	3,656	3,293	3,292	3,148	$\boxed{3,148}$
(LB)	(8,060)	(7,260)	(7,260)	(6,940)	(6,940)
AR	14	14	14	14	14
DOC-1 -- ¢/ASSM.	$\boxed{1.473}$	1.477	1.477	1.500	1.500
DOC-2 -- ¢/ASSM.	1.642	$\boxed{1.629}$	1.629	1.643	1.643
DOC-4 -- ¢/ASSM.	1.977	1.935	$\boxed{1.935}$	1.935	1.935
DOC-10 -- ¢/ASSM.	2.985	2.851	2.851	$\boxed{2.805}$	2.805
$W/S_{T.O.}$ - KG/SQ.M.	391	387	387	371	371
(LB/SQ.FT)	(80.0)	(79.2)	(79.2)	(76.0)	(76.0)
INST. THRUST/ENG. - KN	40.1	37.8	37.8	35.6	35.6
(LB)	(9,019)	(8,502)	(8,502)	(7,996)	(7,996)
CRUISE POWER %	90	80	80	70	70
90 EPNdB AREA - SQ. KM	1.30	1.30	1.30	1.30	1.30
(ESTIMATE) (SQ. MI)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
		IDENTICAL AIRPLANE		IDENTICAL AIRPLANE	

TABLE 0.VIII: T-56 AND QUIET PROPELLER - 910 M (3000 FT) F.L.

	LIFT CONCEPT	NO. ENG.	FPR	FIELD LENGTH M (FT)	CRUISE SPEED	PAX	DOC-2 ¢/ASSM	FUEL KG (LB)
MIN DOC-2 CASE:								
MIN DOC FOR FAR36-5	MF	2	1.47	1,830 (6,000)	0.75	148	~1.59	–
	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR FAR36-10	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR FAR36-15	MF	2	1.35	1,220 (4,000)	0.75	148	1.641	4,318 (9,519)
MIN DOC FOR 95 EPNdB @ 152 M (500')	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR 80 EPNdB @ SPERRY BOX SIDELINE	OTW/IBF	4	1.25	910 (3,000)	0.75	50	3.87	2,223 (4,900)
MIN DOC FOR 80 EPNdB @ SPERRY BOX FLYOVER	OTW/IBF	4	1.25	610 (2,000)	0.75	5-10	7+	
MIN DOC-2 FOR 90 EPNdB FOOTPRINT:								
2.60 SQ. KM (1 SQ.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
1.3 SQ. KM (0.5 SQ.MI.)	MF (0.526)	2	1.35	1,220 (4,000)	0.75	148	1.641	4,318 (9,519)
.83 SQ. KM (0.32 SQ. MI.)	OTW/IBF (WITH SPLITTERS)	4	1.35	910 (3,000)	0.75	148	1.863	4,790 (10,560)
.75 SQ. KM (0.29 SQ. MI.)	MF	4	1.25	1,220 (4,000)	0.65	148	1.887	4,027 (8,877)
MIN DOC-2 FOR 90 EPNdB FOOTPRINT LENGTH:								
6.48 KM (3.5 N.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
3.704 KM (2.0 N.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
1.85 KM (1.0 N.MI.)	OTW/IBF	2	1.35	< 910 (3,000)	0.75	148	1.90	6,350 (14,000)
1220 M (4000 FT)	OTW/IBF	2	1.25	610 (2,000)	0.75	148	2.3	6,804 (15,000)

TABLE 0.IX: DOC AND FUEL PENALTIES - NO PERFORMANCE CONSTRAINTS

penalty indicated for DOC-2 or fuel. For purposes of further comparisons, the 1830 m. (6000 ft.) MF airplane is used as a basis for expressing penalties. If field lengths for short haul aircraft are restricted to 1220 m. (4000 ft.) or less, as suggested throughout the study, the penalties for meeting the different potential requirements are those indicated in Table 0.X. Most of the cases are best satisfied with MF aircraft. Significant increases in DOC and fuel penalties are indicated if 90 EPNdB requirements of less than 1.0 sq. Km. (0.39 sq. mi.) area, or 2.3 Km. (7500 ft.) footprint length are imposed. As noted, the 80 EPNdB STOLport requirement designated 'Sperry box' calls for a very small airplane probably designed for low wing loading and short stage lengths. This requirement does not appear compatible with the high density scenario although it may become feasible for commuter operations.

The penalties for different noise requirements with field length restricted to 910 m. (3000 ft.) are given in Table 0.XI. This comparison was also restricted to designs for Mach 0.75 cruise speed. The low wing loading mechanical flap aircraft designed to cruise at Mach 0.70 would be approximately one percent lower in DOC and nine percent better in fuel consumption. It is concluded that most of the prospective noise requirements can be met with 910 m. (3000 ft.) aircraft at a total penalty of 17 percent compared with a 1830 m. (6000 ft.) airplane. Penalties for mechanical flap and hybrid OTW/IBF are about equal from the standpoint of noise level and direct operating cost at twice 1972 fuel prices; the hybrid is superior in fuel consumption and its DOC would become superior with further increases in fuel price.

It is suggested that attention be given to restricting the 90 EPNdB contour to one sq. Km. (0.39 sq. mi.) in area and 2.3 Km. (7500 ft.) in length. Cost and fuel penalties increase for more stringent requirements. Shorter footprint lengths would require shorter field length requirements and would change the optimum design from four to two engines in the OTW/IBF aircraft.

The effect of field length on direct operating costs and fuel consumption can be summarized for three potential noise requirements as follows (Ref. is the 1830 m. (6000 ft.) aircraft meeting FAR 36-10):

	Lift Concept	No. of Engines	Engine FPR	Field Length m (ft)	Cruise Speed M	DOC 2 Penalty %	Fuel Penalty %
Reference	MF	2	1.35	1830 (6000)	0.75	0	0
FAR 36 - 10 - 15	MF	2	1.35	1220 (4000)	0.75	3.0	4.3
95 EPNdB @ 152m (500 FT.)	MF	2	1.32	1220 (4000)	0.75	4	5
90 EPNdB Footprint							
Area = 2.60 Km^2 (1.00 sq mi)	MF	2	1.40	1220 (4000)	0.75	3	4
1.30 Km^2 (0.50 sq mi)	MF	2	1.33	1220 (4000)	0.75	4	5
0.83 Km^2 (0.32 sq mi)	OTW/IBF	4 Splitler	1.35	910 (3000)	0.75	17	14
0.75 Km^2 (0.29 sq mi)	MF	4	1.25	1220 (4000)	0.65	18	(- 4)
90 EPNdB Footprint							
Length = 1.85 Km (1.0 n.m.)	OTW/IBF	2	1.35	850 (2800)	0.75	20	50
1220m (4000 FT)	OTW/IBF	2	1.25	610 (2000)	0.75	40	60
Sperry Box - 80 EPNdB	Small airplane with low wing loading designed for short stage lengths					400	200 (per passenger)

TABLE 0.X DOC AND FUEL PENALTIES @ FIELD LENGTH 1220 M (4000 FT) OR LESS

NOISE REQUIREMENT	LIFT CONCEPT	NO. OF ENGINES	ENGINE FPR	FIELD LENGTH m. (FT.)	DOC-2 PENALTY PCTG	FUEL PENALTY PCTG
REFERENCE	MF	2	1.35	1830 (6000)	0	0
FAR 36 - 10 OR 15	MF*	2	1.35	910 (3000)	15	27
FAR 36 - 15	OTW/IBF	4 (SPLITTER)	1.35	910 (3000)	17	14
95 EPNdB @ 152 m.(500 FT.)	OTW/IBF	4	1.35	910 (3000)	15	6
90 EPNdB AREA						
2.6 SQ. Km (1 SQ.MI.)	MF*	2	1.40	910 (3000)	14	27
1.3 SQ. Km (0.5 SQ.MI.)	OTW/IBF	4	1.37	910 (3000)	15	6
0.83 SQ. Km (0.32 SQ.MI.)	OTW/IBF	4 (SPLITTER)	1.35	910 (3000)	17	14
90 EPNdB LENGTH						
2.3 Km (7500 FT.)	OTW/IBF	4 (SPLITTER)	1.35	910 (3000)	17	14
1.86 Km (1 N.MI.)	OTW/IBF	2	1.35	850 (2800)	20	50
1.22 Km (4000 FT.)	OTW/IBF	2	1.25	610 (2000)	40	60

* MF AT LOW WING LOADING REQUIRES RIDE QUALITY GUST ALLEVIATION AND DEMONSTRATION FOR PASSENGER ACCEPTABILITY ON LONGER STAGE LENGTHS.

TABLE 0.XI DOC AND FUEL PENALTIES @ FIELD LENGTH 910 m. (3000 FT.) OR LESS -- M 0.75

Field Length		% Penalties for Meeting					
Meters	Feet	FAR 36-15		1 sq. Km 90 EPNdB		90 EPNdB 2.3 Km Long	
		DOC	Fuel	DOC	Fuel	DOC	Fuel
1830	6000	3	4	10	10	17	14
1220	4000	3	4	10	10	17	14
915	3000	17	14	16	10	17	14

To meet FAR 36 minus 15, the landing field length must be reduced below 1830 m. (6000 ft.) because of approach noise. If the requirement is one sq. Km for the 90 EPNdB footprint area, the penalty is 10 percent in DOC and fuel and no additional penalty is incurred for reduction in field length to 1220 m. If the length of the 90 EPNdB footprint is required to be 2.3 Km. the 910 m. (3000 ft.) field length is required and the DOC and fuel penalties are 17% and 14% respectively.

Table 0.XII summarizes the characteristics of aircraft designed for 610 and 910 meter field lengths. As noted previously, the AW and EBF aircraft represented here have about the same noise characteristics as the OTW/IBF aircraft with 1.35 FPR engines. Their direct operating costs are 10 to 11 percent higher. Penalties for meeting noise requirements would be increased to approximately double those listed in the above discussions.

Further comparison of the MF and OTW/IBF aircraft is shown in Figure 0.13 for 0.75 M designs on the basis of fuel and field length. The 4-engined OTW/IBF is clearly superior to the MF at field lengths shorter than 1070 m. (3500 ft.) while the 4 engined MF is superior at field lengths longer than 1220 m. (4000 ft.). However, it should be noted that minimum DOC's are achieved with the 2-engined, rather than the 4-engined MF and therefore the primary comparison should be between the 4-engined OTW/IBF and the 2-engined MF. The direct operating costs of these concepts are presented in Figure 0.14 for 0.75 and 0.8 M and as a function of field length. At 910 m. (3000 ft.) and DOC-1, the OTW/IBF is superior at 0.8M, while the MF is slightly superior at 0.75 M. For DOC-2, the OTW/IBF is superior at 0.8 M, while the concepts are equal at 0.75 M.

FIELD LENGTH	610 M (2000 FT)				910 M (3000 FT)			
CONCEPT	NO. OF ENG. (FPR)	M	FUEL KG (LB)	DOC-2 ¢/ASSM	NO. OF ENG. (FPR)	M	FUEL KG (LB)	DOC-2 ¢/ASSM
OTW/IBF	4 (1.35)	0.75	4,944 (10,900)	1.961	4 (1.35)	0.75	4,400 (9,700)	1.831
	—	—	—	—	4 (1.47)	0.75	5,117 (11,280)	1.820
MF	—	—	—	—	2 (1.35)	0.70	5,089 (11,220)	1.818
AW	—	—	—	—	2 + 2 (1.35/3.0)	0.75	5,688 (12,540)	2.015
EBF	4	0.65	5,003 (11,030)	2.196	4 (1.25)	0.65	4,427 (9,760)	2.046
DEFLECTED SLIPSTREAM	—	—	—	—	4 (T-56)	0.55	3,293 (7,260)	1.629

TABLE 0.XII SUMMARY OF 610 M AND 910 M (2000 AND 3000 FT) AIRCRAFT (MIN. DOC 2)

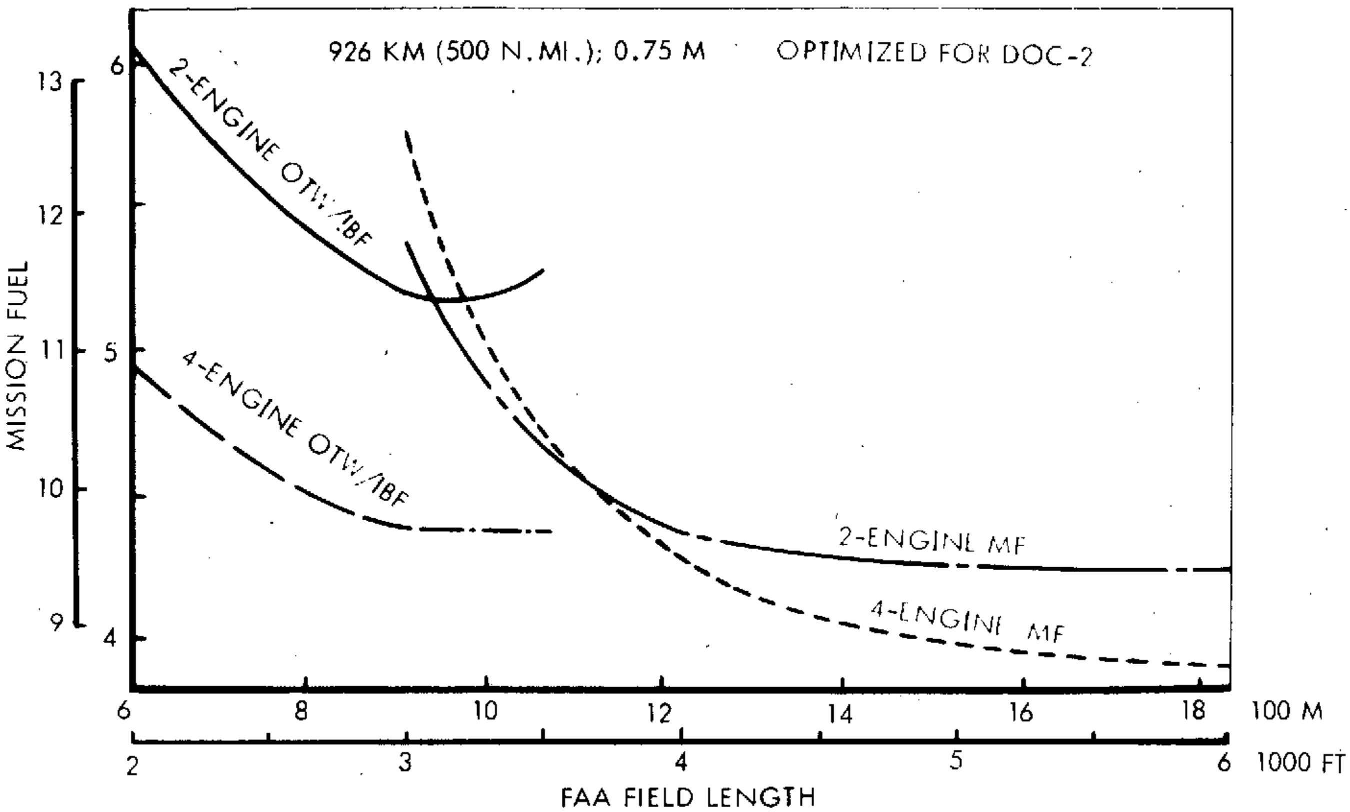


FIGURE 0.13: EFFECT OF FIELD LENGTH ON MISSION FUEL

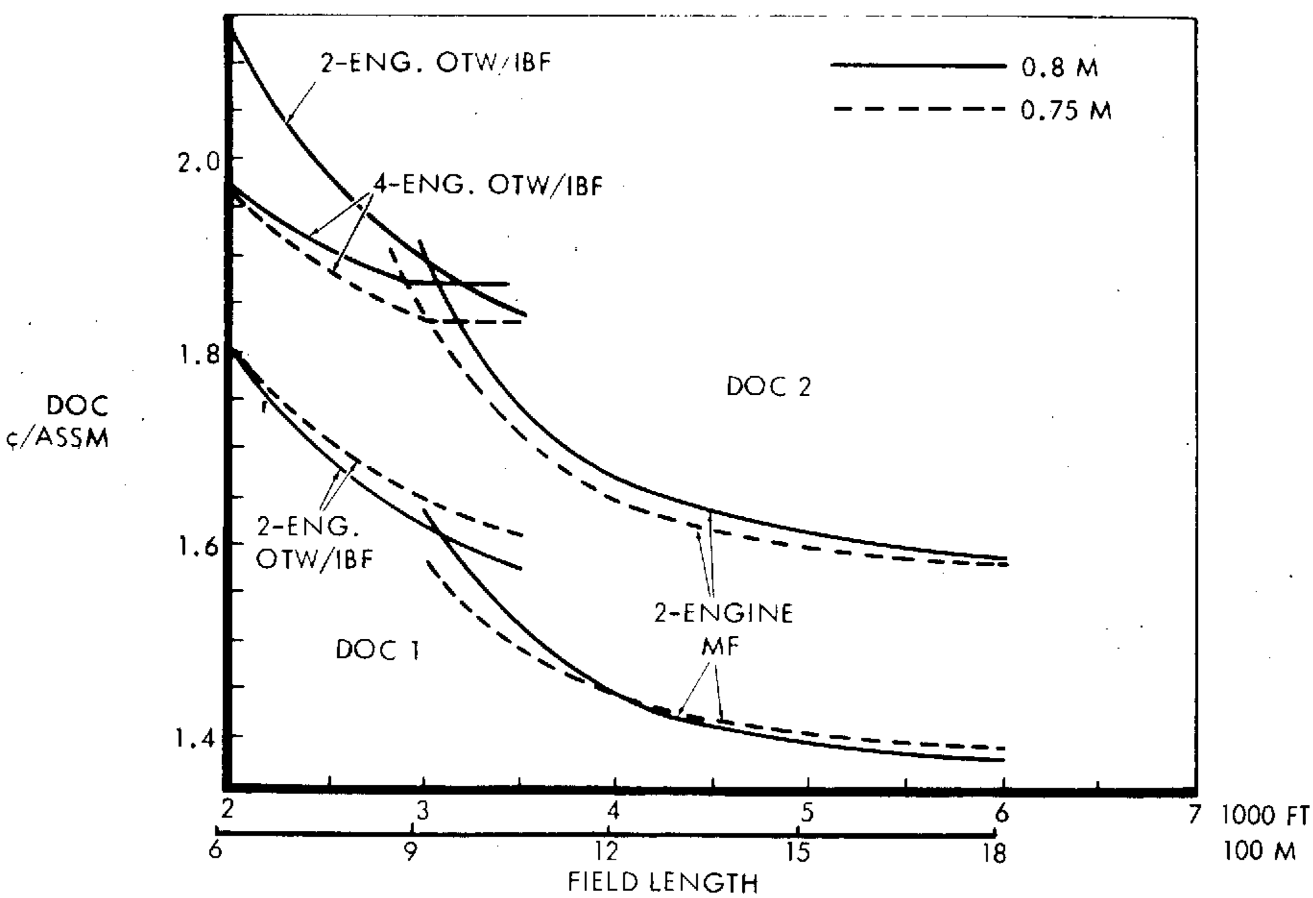


FIGURE 0.14: EFFECT OF FIELD LENGTH ON DOC

The choice of lift concept for 610 m. (2000 ft.) field length is clear cut; the four-engine hybrid OTW/IBF has a DOC-2, 23 percent higher than the 1829 m. (6000 ft.) MF airplane and 7 percent higher than the 910 m. (3000 ft.) hybrid. Previous estimates of the penalty of reduction in field length from 910 m. to 610 m. were 15 percent (Ref. 1) and 20 percent (Ref. 3). Whereas the former estimates represented a DOC penalty of 50 percent over CTOL, the current conservative optimization of the hybrid OTW/IBF indicates that 610 meter field performance may well be economically viable. These results would have significant consequences in conserving real estate.

The configuration selection for 910 m. (3000 ft.) is not clear cut; since there is no demand currently for an implementation decision, it is suggested that several years are available in which additional data can be made available, such as the following:

- Clarification of the land-side costs and needs for congestion relief associated with 610 m. to 1220 m. (2000 to 4000 ft.) short haul runways.
- Demonstration of the gust alleviation technology and passenger acceptance of associated ride quality for an airplane with 293 Kg/m^2 (60 psf) wing loading.
- Further development and demonstration of propulsive lift.
- Establishment of rational specific noise criteria for long haul aircraft using existing runways and for short haul aircraft using additional runways not now contributing to community noise.
- Establishment of specific performance certification criteria (modification and implementation of a modified FAR Part XX).
- Experimental verification of the potential for further improvement in the performance attainable in the hybrid OTW/IBF concept.

On the latter point, the long duct nacelle used conservatively in the performance analyses causes high losses in cruise. There is considerable potential for improvement in this area but experimental data are lacking. An improvement of 15 percent in DOC and 10 percent in fuel consumption was estimated for an engine arrangement which avoids the long exhaust duct. Improvement less than this magnitude, if verified experimentally, would make the OTW concept (possibly combined with IBF) an overwhelmingly superior approach at all field lengths up to 6000 feet.

It is concluded that the hybrid OTW/IBF concept with design cruise speed of Mach 0.75 and FPR 1.35 engines should be considered the best potential solution for 910 m.(3000 ft.) or shorter field performance on the basis of lower fuel consumption and further potential for improvement. The versatility of full-load, longer range performance should be incorporated; using CTOL runways; a 2780 Km (1500 n.mi.) range can be provided with a takeoff field length of 1280 m. (4200 ft.). If 1.35 FPR engines with 57.8 KN (13,000 lb.) thrust were developed, aircraft sized for 90, 120, or 150 passengers could be designed with 2, 3, or 4 engines.

Recommended Compromise Concept

The potential of the hybrid OTW/IBF for both 610 and 910 m. (2000 and 3000 ft.) field lengths and small noise footprints indicates that it should be pursued in research and development programs. Implementation decisions are downstream so that confirmation of the results of current analyses can be obtained and a minimum risk program could be initiated in the 1980's. Decisions and actions which are appropriate are the following:

- Continuation of the Quiet STOL Research Airplane program.
- Implementation of further analytical and experimental development of improved nacelle and engine installation with emphasis on improving cruise performance and determining the optimum combination of high speed and low speed installation approaches.
- Analytical refinement of engine design characteristics through an integrated airframe/engine study in the fan pressure ratio range of 1.3 to 1.4 for noise.
- Initiation of a quiet R/STOL engine development with technology drawn from the QCSEE program and guidance from the integrated airframe/engine study.

Figure 0.15 summarizes the conclusions of the fuel conservation portions of the study by indicating the available fuel savings and the associated DOC and speed penalties at 1830 m. (6000 ft.) and 910 m. (3000 ft.) field lengths. Figure 0.16 summarizes the comparison of OTW/IBF and MF concepts at 910 m. (3000 ft.) field length from which it can be concluded that the OTW/IBF is economically superior in fuel and DOC at field lengths below 910 m. (3000 ft.) while the MF is superior at field lengths greater than 910 m. (3000 ft.). At 910 m. (3000 ft.) the OTW/IBF is considered superior because of its better fuel consumption, better ride quality, and greater potential for improvement. Figure 0.17 summarizes the conclusions regarding aspect ratio effects and the EBF, AW, and deflected slipstream lift concepts.

The recommendations regarding the desirable engine fan pressure ratio and additional Research and Development are summarized in Figures 0.18 and 0.19 while the recommendations regarding noise requirements are summarized in Figure 0.20.

- AT 1830 M (6000 FT) F.L.,
  - o 926 KM., MISSION FUEL CAN BE REDUCED BY UP TO 24% AT THE EXPENSE OF A 31% REDUCTION IN SPEED AND A 15% INCREASE IN DOC-2 (20% IN DOC-1).
  - o BY OPTIMIZING FOR DOC-2, MISSION FUEL CAN BE REDUCED BY 5% FOR THE SAME DOC-2 AND A 7% REDUCTION IN SPEED
- AT 910 M (3000 FT) F.L.,
  - o MISSION FUEL CAN BE REDUCED BY UP TO 20% AT THE EXPENSE OF A 31% REDUCTION IN SPEED AND A 12% INCREASE IN DOC-2 (18% IN DOC-1).
  - o BY OPTIMIZING FOR DOC-2, MISSION FUEL CAN BE REDUCED 11% FOR THE SAME DOC-2 AND 7% REDUCTION IN SPEED.
- 0.75 M AND OPTIMIZATION FOR DOC-3 ARE RECOMMENDED FOR FUTURE SHORT HAUL TRANSPORTS

FIGURE 0.15: SUMMARY OF RESULTS -- FUEL CONSERVATION

- o AT 910 M (3000 FT) F.L.,
  - o OPTIMIZED FOR DOC1 AT 0.8M, THE OTW/IBF HAS 1% BETTER DOC AND 1% BETTER FUEL CONSUMPTION THAN MF.
  - o OPTIMIZED FOR DOC2 THE OTW/IBF HAS 1% POORER DOC, 9% BETTER FUEL CONSUMPTION & 7% HIGHER SPEED THAN MF.
  - o OPTIMIZED FOR DOC4, THE OTW/IBF HAS 2% BETTER DOC AND 13% BETTER FUEL CONSUMPTION THAN MF.
  - o OPTIMIZED FOR MINIMUM FUEL, BOTH CONCEPTS ARE EQUAL.
  - o OTW/IBF HAS BETTER RIDE QUALITIES THAN MF.
- o AT > 910 M THE MF IS BETTER THAN OTW/IBF IN BOTH FUEL CONSUMPTION AND DOC.
- o AT < 910 M THE OTW/IBF IS BETTER THAN MF IN BOTH FUEL CONSUMPTION AND DOC.

FIGURE 0.16: SUMMARY OF RESULTS - COMPARISON OF OTW/IBF AND MF

- TO MINIMIZE FUEL CONSUMPTION ASPECT RATIOS UP TO 14 ARE REQUIRED.
- TO MINIMIZE DOC 2 ASPECT RATIOS OF 10 TO 12 ARE REQUIRED.
- THE AW & EBF CONCEPTS ARE NOT RECOMMENDED.
- THE T-56 TURBOFAN DEFLECTED SLIPSTREAM DESIGN PROVIDES BETTER FUEL AND DOC ECONOMY THAN THE FAN-ENGINED DESIGNS AT LESS THAN 1520 M (5000 FT) FIELD LENGTH
- AN ADVANCED TURBO-PROP HAS NO ADVANTAGE OVER T-56 EXCEPT FLEXIBILITY IN SIZING AIRCRAFT DUE TO DEVELOPMENT COST.

FIGURE 0.17: SUMMARY OF RESULTS - ASPECT RATIO AND OTHER CONCEPTS

- 1.35 FPR IS RECOMMENDED
  - IT PROVIDES GOOD FUEL & DOC ECONOMICS AT PRESENT AND INFLATED FUTURE FUEL PRICE LEVELS.
  - IT CAN MEET THE PROPOSED NOISE REQUIREMENTS.
  - PRELIMINARY ANALYSES INDICATE IT IS AN EXCELLENT ENGINE FOR FUTURE CTOL AIRPLANES OPTIMIZED FOR INCREASED FUEL PRICE.
- ADDITIONAL STUDY AND R AND D IS NEEDED:
  - COMMONALITY OF 1.35 FPR ENGINE FOR BOTH SHORT-HAUL AND LONGER-RANGE MISSIONS.
  - FUEL AND ECONOMICS OF INTERMEDIATE AND LONG-RANGE COMMERCIAL AIRCRAFT RELATED TO FUTURE NOISE CRITERIA.
  - LOW WING LOADING AIRCRAFT FOR LOWER DENSITY SHORT-HAUL ARENA.
  - ENGINE DESIGN INTEGRATED WITH AIRCRAFT OPTIMIZATION FOR REFINEMENTS OF FPR, FAN STAGES, GEARING OR NOT, VARIABLE PITCH OR NOT.

FIGURE 0.18: RECOMMENDATIONS - ENGINE AND AIRCRAFT

- CONTINUE SUPERCRITICAL AIRFOIL TECHNOLOGY AT SPEEDS BELOW M 0.8.
- DEVELOP HIGH ASPECT RATIO TECHNOLOGY (M 0.75)
- CONTINUE PROPULSIVE LIFT RESEARCH -- NOT FOR EARLY APPLICATION TO SPECIFIC STOL DESIGNS, BUT TO REFINE HIGH LIFT TECHNOLOGY FOR STOL, RTOL, AND CTOL.
- INCREASE RESEARCH ON GUST ALLEVIATION/RIDE QUALITY FOR MECHANICAL FLAP AIRPLANES WITH W/S OF ABOUT 40 TO 80.
- ADDITIONAL ANALYSIS OF ADVANCED ENGINE CHARACTERISTICS FOR FUEL CONSERVATION.

FIGURE 0.19: RECOMMENDATIONS - TECHNOLOGY

- PART 36 - 10 dB FOR CTOL, LONG RANGE MISSIONS
- LESS THAN 2.6 SQUARE KILOMETERS (1/4 SQUARE STATUTE MILE), 90 EPNdB FOOTPRINT AREA BEYOND EACH END OF THE RUNWAY.
- LESS THAN 1.6 KILOMETERS (1 STATUTE MILE), 90 EPNdB FOOTPRINT LENGTH BEYOND EACH END OF THE RUNWAY
- SPERRY BOX 80 EPNdB LEVEL IS NOT FEASIBLE OR APPLICABLE IN HIGH-DENSITY SHORT-HAUL
- 500 FT SIDELINE IS NOT RECOMMENDED - NOT PERTINENT FOR RELIEF OF CONGESTION AT HUB AIRPORTS OR USE OF SECONDARY AIRPORTS
- STUDY OF LAND-SIDE ECONOMICS OF PROVIDING TERMINAL FACILITIES COMPATIBLE WITH THESE SUGGESTED NOISE CRITERIA

FIGURE 0.20: RECOMMENDATIONS - NOISE REQUIREMENTS

5.0 AUGMENTOR WING (AW) VEHICLES

5.1 AW CONCEPT

Four engine augmentor wing vehicles were considered in reference 2 in which a point design was configured for a field length of 610m (2000 ft.) with a parametric excursion to 910m (3000 ft.). Although the DOC of the latter was indicated to be inferior to that of either the MF or the hybrid OTW-IBF concepts at the same field length, it was not ascertained whether a two engine AW configuration would amend this conclusion. Accordingly, the AW concept has been retained in subsequent studies to explore the possible advantages of a twin-engine configuration for 910m (3000 ft.) field performance. A further objective was the provision of reference AW data for perspective on other lift systems. Because of the extensive technology data base which has accumulated in the course of NASA funded research, the AW concept is particularly appropriate as a standard by which competing lift concepts may be judged.

Baseline Mission - The major part of the AW studies accomplished under the present study have concerned the baseline mission derived in reference 2, i.e., 910m (3000 ft.) field length vehicles with a capacity payload of 148 passengers which is associated with a design range of 926km (500 n.m.) and an initial cruise altitude of 9140m (30,000 ft.) at Mach 0.8. Vehicles have been optimized in this mission context on the basis of minimum operating cost at a fuel price of 11.5¢/gallon and are described in Section 5.4. As in the case of the other baseline mission vehicles using the OTW-IBF and MF lift concepts, all have a fuselage seating 6 abreast in a single aisle arrangement and have high wing, tee-tail configurations with fuselage mounted landing gear. The high lift system comprises a 30% (retracted) chord augmentor flap having a telescoping leading edge on the shroud and segmented intake doors (as developed by Boeing in the studies reported in reference 32) and wing leading edge blowing. An augmentor nozzle array area ratio of 6 is assumed. In order to maximize the installed thrust limitation per unit wing area (T/S) and thus enable the higher wing loadings which minimize DOC to be attained, a compound taper wing with optimum nacelle locations have been adopted. This implies the use of an overwing nacelle mounting at the preferred aspect ratio.

Fuel-Conservative Vehicles - The AW vehicle has also been evaluated in the context of minimum fuel consumption, but to a lesser degree than other lift concepts. In this case near optimum mission and configuration parameters have been identified for minimum DOC at 1972 fuel prices, for variable fuel prices and for minimum mission fuel. Thus, direct comparisons with the MF and OTW-IBF fuel conservative vehicles are possible. Notwithstanding the weight and surface area advantages of the 5 abreast fuselage seating arrangement which have been incorporated in the other fuel conservative lift concepts, augmentor duct stowage considerations preclude the wing mounted landing gear and low wing arrangement, which the longer fuselage requires, for the AW. Thus, the fuel conservative AW vehicles have a generally similar configuration to the baseline mission vehicles. However, their higher aspect ratio permits a more conventional pylon-mounted nacelle under the wing.

The augmentor wing aircraft as previously described exhibits a characteristically high fuel consumption relative to other high lift concepts because of the required higher pressure ratio engine which the concept necessitates and is further aggravated by part power cruise operation. Moreover the T/S limits imposed by the ducting preclude the adoption of the high wing loading which is conducive to both low fuel consumption (high cruise L/D) and low operating cost. Accordingly, a brief examination was made of a "hybrid augmentor wing concept" using low FPR (1.35) cruise propulsion engines and high FPR (3.0) load-compressors to supply the augmentor airflow and supplement thrust in the STOL mode. Although the load compressors are of a size which ostensibly would permit their underfloor installation in the fuselage for a low wing configuration, the undesirability of routing high pressure ducts through primary structural boxes to avoid the incursion of a wing-mounted landing gear, has dictated the selected high wing arrangement.

Two load-compressor engines have been assumed in these conceptual studies and are essentially small scale versions of the PD287-51 QCSEE engine. Preliminary estimates have indicated that greater compressor power extraction from the core with the addition of a further turbine stage could not be obtained economically. The optimum load compressor location from duct sizing consideration would be on the aircraft centerline but the selected wing root location is dictated by the practical considerations of engine removal without the use of overhead gantries or other specialized equipment not normally available in a terminal area.

AW Ducting Configuration - Independent AW duct systems have been assumed for both two- and four-engine configurations as illustrated in Figures 147 and 148, since no significant net advantage can be identified for the plenum arrangement at 3000 ft. field length were the technical problems of the latter to be resolved satisfactorily. However, a plenum duct system is used for the fan flow to the wing leading edge and aileron BLC system.

The use of a plenum duct for the augmentor wing is currently restricted by two considerations:

- The excess nozzle area per live engine which follows an engine failure if no provision is made for area compensation. Detroit-Diesel-Allison has suggested that nozzle area per live engine should be controlled within 5% in these circumstances which would ostensibly permit up to 15% of the fan flow per engine to be ducted by a common plenum in a four-engine arrangement; only 5% would be permitted in the corresponding two-engine arrangement.
- The possibility of unstable engine operation when multiple engines have a common fan delivery duct. The effect of any commonality in delivery ducting is to make the effective nozzle area presented to any engine a function of the differences

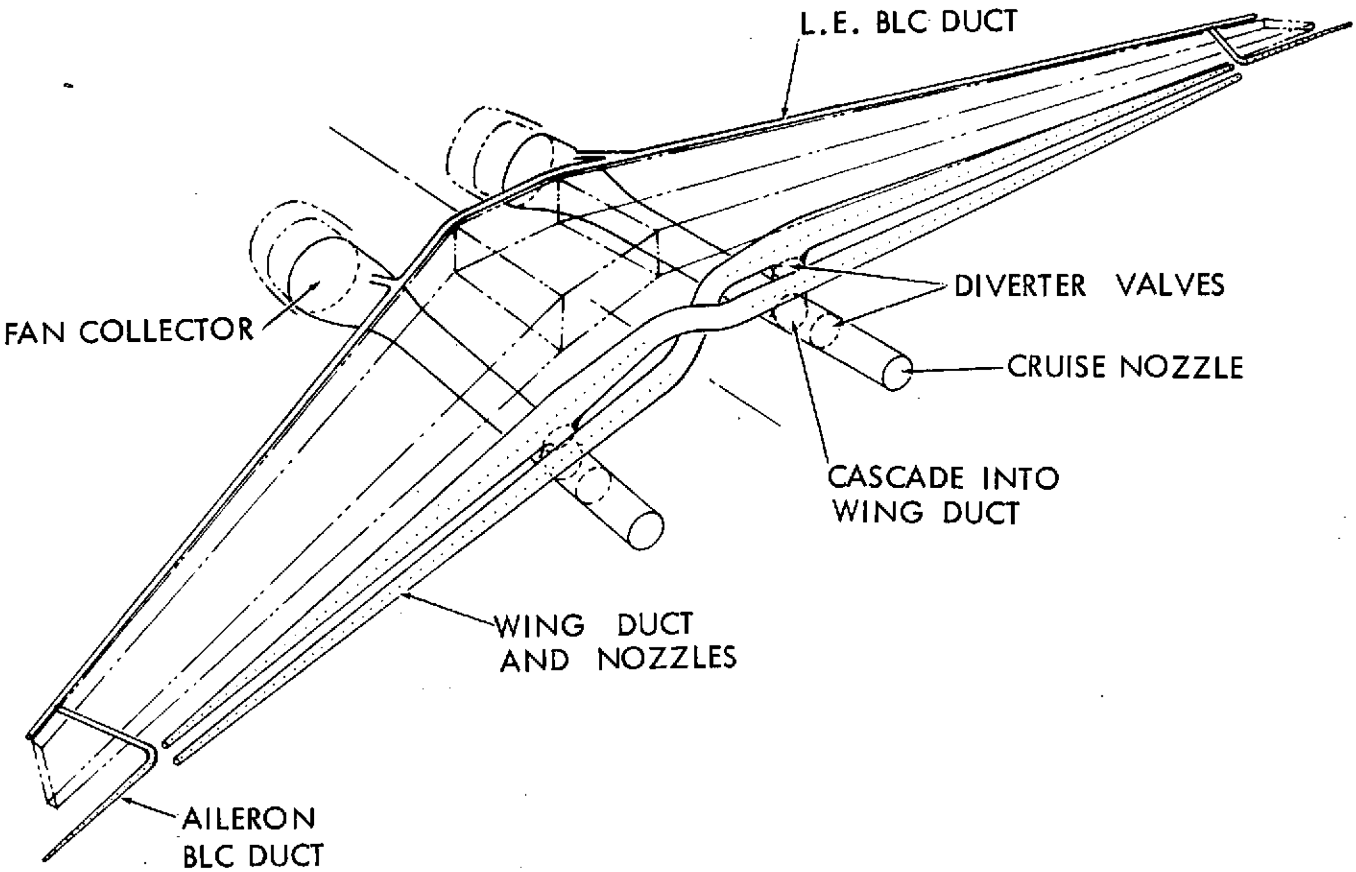


FIGURE 147: AW - INDEPENDENT DUCT SYSTEM (2-ENGINES)

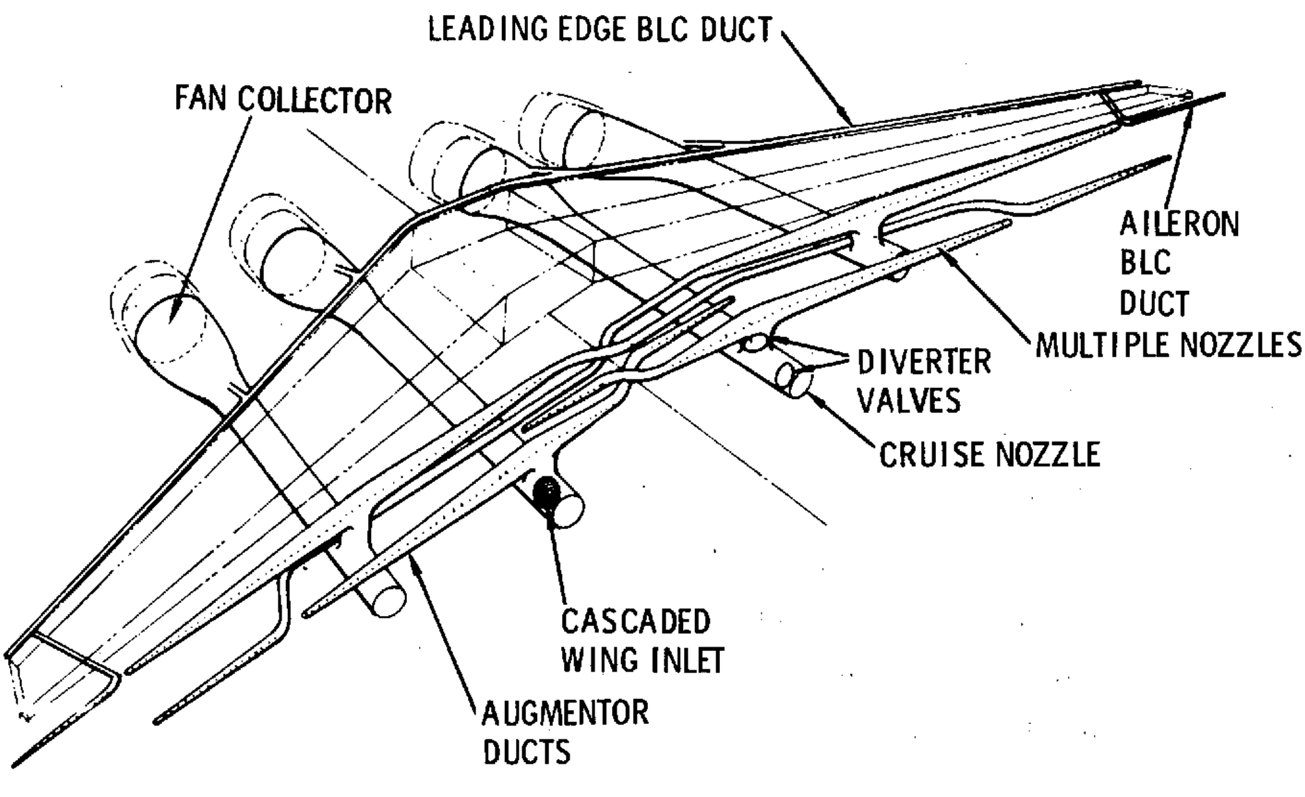


FIGURE 148: AW - INDEPENDENT DUCT SYSTEM (4-ENGINES)

in delivery pressure and mass flow between individual engines. The average nozzle area per engine cannot vary and thus, to a first approximation, the plenum duct pressure is not greatly affected by any slight asymmetry between leading and lagging engines. However, the proportion of the total nozzle area supplied by the leading engines will increase and the lagging engine nozzle area will diminish correspondingly. Hence, the leading engines tend to overspeed due to excess nozzle area and the lagging engine will be driven towards a surge condition since it cannot relieve itself of the back pressure in proportion to its reduced mass flow.

In order to overcome the first objection in a two-engine augmentor system, it would be necessary to subdivide the ducting into primary and subduct elements of which the primary duct would be sized to cater for the engine-out flow and would be isolated from the subduct for single engine operation as indicated in Figure 149. However, the division of the system into full flap-span ducts of equal size results in duct proportions which are identical with those for independent ducts. Hence, there is no possible advantage to be gained from plenum ducting for a two-engine installation. In the case of a four-engine installation, although the T/S limit does restrict the wing loading which can be obtained it does not have any substantial impact on the attainable DOC for 3000 ft. field length since the slope of the field constrained cost curve is small in the region of the T/S limited wing loading. Hence, the potential advantages of a plenum system are largely academic for field lengths of 3000 ft. (or more) and chiefly relate to the ride quality (although there is no suggestion that the ride quality warrants the effort of developing a plenum system to improve it).

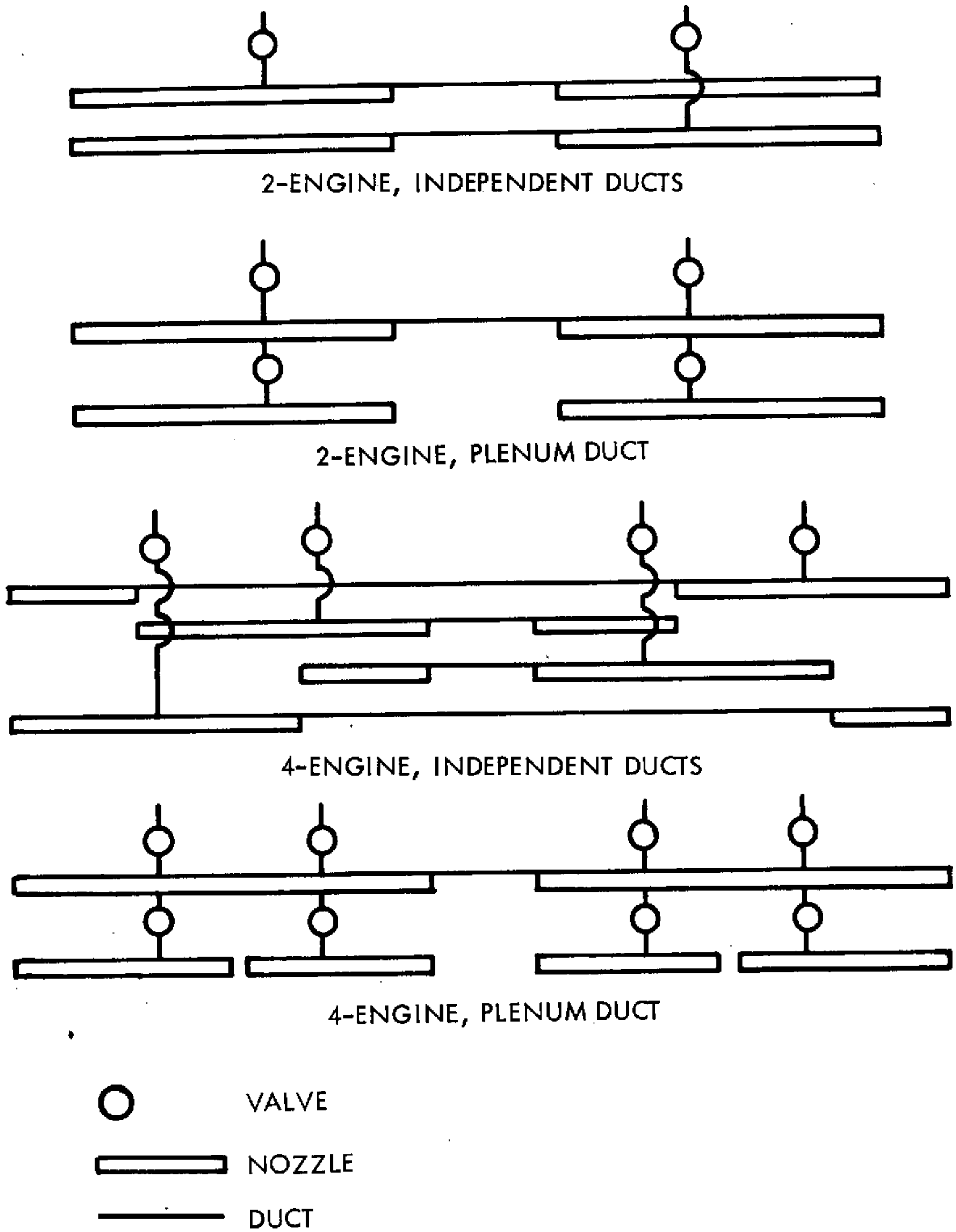


FIGURE 149: AUGMENTOR WING DUCTING ARRANGEMENTS

5.2 AW PROPULSION SYSTEM DATA

5.2.1 Candidate Engines

The candidate engines and power plant systems selected for the Augmentor Wing airplane portion of this study effort are listed on Table XII. These propulsion systems are based on the NASA-Lewis QCSEE study, Detroit Diesel Allison (DDA) updated data, and NASA CR-114570. The technology level assumed for these engines is consistent with that assumed for the OTW/IBF candidates of Section 4.2.1, i.e. mid 1980's. The FPR 3.0 turbofan engine used for the AW airplanes reported in NASA CR-114612 was retained for baseline mission vehicles. Subsequently, an update to this engine was received from DDA which improved the basic performance approximately five percent and was incorporated in fuel conservative vehicles. To examine other turbofan cycle variations, FPR 3.2 engine data from an AW study conducted by Boeing for NASA-Ames (reported in NASA CR-114570) were also introduced into the study of fuel conservative vehicles. This engine is the Pratt and Whitney STF395D with cycle modifications introduced by Boeing for study purposes and designated by the suffix (BM-2). The candidate turbofan engines are compared with other '1980' engines of similar cycle and characteristics in Figure 150 which indicates the candidates to have an equivalent or better level of technology than the average.

The generally inferior performance of the AW airplane by comparison with less well-developed lift concepts in previous studies has prompted an optimistic assessment of AW engine performance characteristics for an equitable comparison. Study of the AW engine installation since the publication of CR-114612 has now indicated that the installed performance and weight penalties were slightly underestimated in that report. Inasmuch as the additional degradations are generally small but are consistent with an optimistic approach, the original installation losses have been retained in subsequent vehicle studies.

The rematched PD 287-51 engine data were derived by application of the 5 percent cruise SFC reduction accompanied by a 7% cruise thrust increase to the basic PD 287-51 data. The limited data available on the STF395D precluded the generation of the full

TABLE XII: AW ENGINE AND POWER PLANT CANDIDATES

FAN PRESSURE RATIO	FAN TYPE	BASED ON ENGINE	
TURBOFAN:			
3.0	F/P	PD287-51	HIGH MACH NUMBER INLET; WALL TREATMENT IN EXHAUST DUCT
3.0	F/P	PD287-51* REMATCHED	HIGH MACH NUMBER INLET; WALL TREATMENT IN EXHAUST DUCT
3.2	F/P	STF395D	HIGH MACH NUMBER INLET; WALL TREATMENT IN EXHAUST DUCT
LOAD COMPRESSOR:			
1.35 (CRUISE ENG)	F/P	PD287-11	WALL TREATMENT ONLY
3.0 (AW POWER SYSTEM)	F/P	PD287-51	SONIC INLET; EXHAUST DUCT WALL TREATMENT

* BASE PD287-51 WITH REMATCHED PRIMARY NOZZLE AREA IN CRUISE MODE; ASSUMES SFC REDUCTION OF 5% WITH NO INCREASE IN ENGINE WEIGHT.

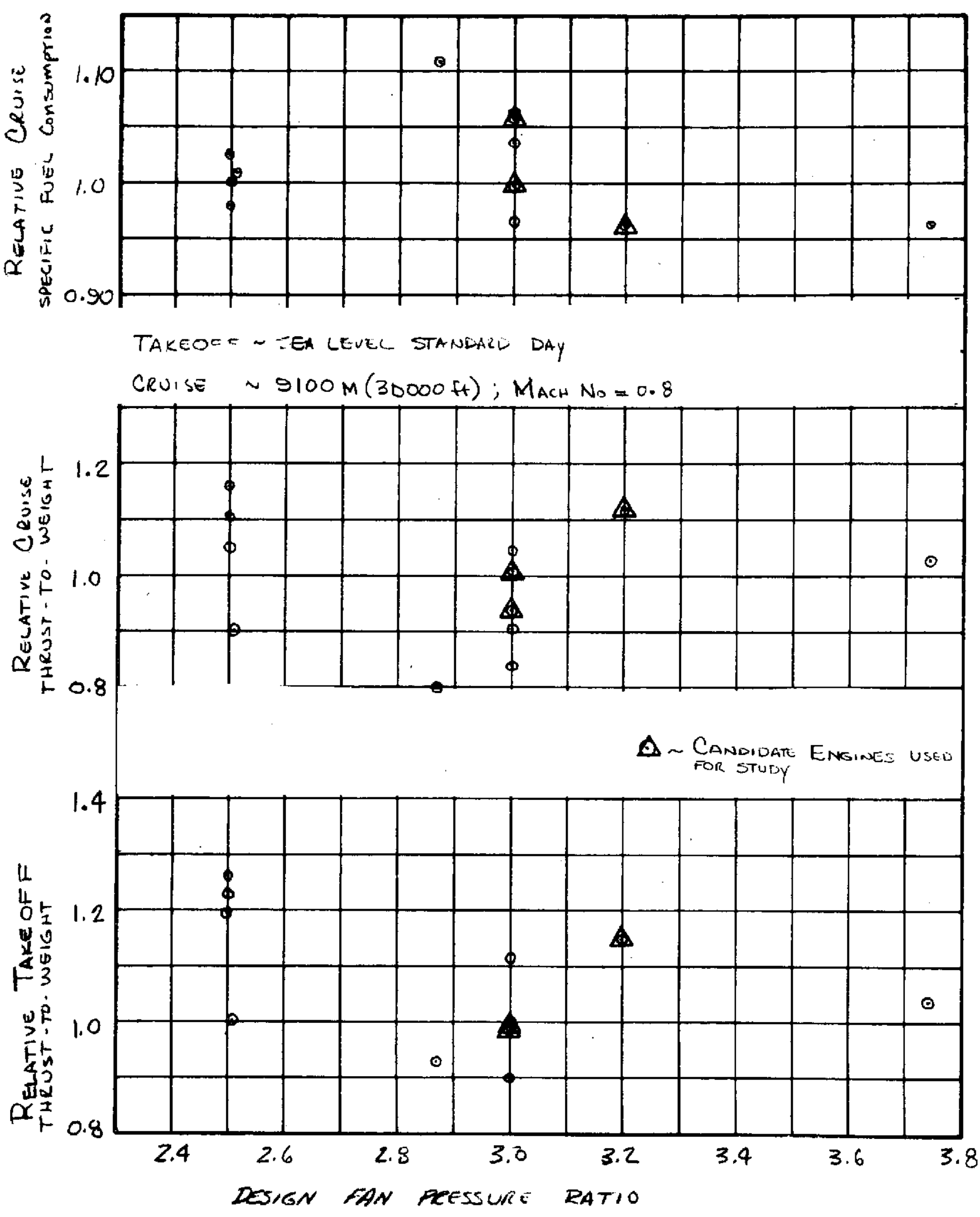


FIGURE 150: AW ENGINE COMPARISONS

performance matrix required for the study. Although it was desired to exploit the potential fuel-saving characteristics of the modified STF395D (BM-2) cycle reported by Boeing Aircraft Company for NASA-Ames in report NASA CR-114570, no data were readily available for this modified cycle other than the limited information contained in that report. Therefore, utilizing the limited STF395D data of the manufacturer and the CR-114570 data for the STF395 (BM-2), factors were derived for application to the baseline PD287-51 to represent the STF395 (BM-2) engine. These factors included lapse rate, SFC and weight data based on a common scaled rated thrust. Table XIII presents comparative data for the baseline PD287-51 engine together with the rematched PD287-51 and the representative STF395 (BM-2) engines. All installed data in this table include nacelle external drag losses as described in paragraph 4.2.2.

As described in Section 5.1, consideration has also been given to the use of MF propulsion engines (described in Section 6.2) and discrete AW load compressors in a hybrid AW concept.

A survey was made of available engine data for a load compressor. The bulk of the engines that have been used for such applications are much too small (beyond the range of reasonable scaling), have too low a fan pressure ratio, are not representative of advanced technology and/or utilize primary exhaust air which is excessively hot for this application. It was concluded that the basic engines selected for the AW study were the most suitable. Of these, the PD287-51 was again selected because of the ready availability of data. The installation of this engine in the load compressor role would not entail performance or weight considerations appreciably different from those of the basic AW installation, i.e. sonic inlet guide vanes, primary nozzle acoustic treatment, etc., and the rematched PD287-51 data were therefore used at base level. External drag terms included in these terminal area data were not considered to compromise the data for this application. Cruise engine data for airplane configurations incorporating the load compressor were taken from 1.35 fan pressure ratio engine data utilized in the MF study airplanes.

ENGINE REPRESENTATION	PD287-51	PD287-51 (Rematched)	STF395D BM-2
FAN PRESSURE RATIO	3.0	3.0	3.2
FAN TYPE	F/P	F/P	F/P
UNINSTALLED T/W (T.O.)*	4.90	4.90	5.72
INSTALLED T/W (T.O.)**	2.87	2.87	3.35
INST. SPEED LAPSE RATE (0.2M)	0.849	0.849	0.849
UNINSTALLED $/LB THRUST (T.O.)*	45.30	45.30	45.30
INSTALLED $/LB THRUST (T.O.)**	65.30	65.30	65.30
INST. ALTITUDE LAPSE 0.8M/30,000' (9144M)	0.275	0.294	0.281
INST. CRUISE SFC, LB/LB/HR 0.8M/30,000' (9144M)	0.968	0.919	0.853

* BASE SIZE - RATED THRUST

** BASE SIZE - S.L., 95°F (35°C)

TABLE XIII: AW ENGINE CHARACTERISTICS (NEAR SONIC INLET)

5.2.2 Installation Performance Characteristics

As part of the NASA-QCSEE study, uninstalled and installed engine data were provided by Detroit Diesel Allison in the form of a computer deck for the PD287-51 engine. Installed engine performance for the AW airplane has been generated using this deck.

The installation aspects of the PD287-51 provided by DDA were reviewed and agree closely with Lockheed evaluations. Comparisons of fan duct pressure losses, fan nozzle velocity coefficients, and nacelle drags used for the AW concept showed close agreement between DDA and Lockheed calculations and were not modified by Lockheed. Propulsion installation penalties used by Lockheed are presented in the following table for maximum cruise at 9,100 m. (30,000 ft.) altitude and 0.8 Mach number:

Installation Parameter	Penalty
Inlet $\Delta P/P$	0.0045
Fan duct $\Delta P/P$	0.061
Primary duct $\Delta P/P$	0.002
Fan nozzle velocity coefficient	0.985
ECS airbleed (Total for 150 PAX)	99.5 Kg/min. (220 lb./min.)
Power extraction (Total for 150 PAX)	104.2 KW (140 HP)
Nacelle external drag - DN/FN	.0825

Note that the inlet recovery value shown above includes only the basic inlet loss, the variable guide vanes employed for sonic inlet acoustic treatment are engine hardware and associated losses are included in basic engine performance data.

Environmental control system airbleed was extracted from the fan discharge rather than the engine core, thereby minimizing the performance penalty for this airbleed. The method of evaluating the performance penalty associated with this airbleed is as described in 4.2.2 and applies only to the climb and cruise data.

The effect of engine scaling on required acoustic treatment and incremental performance losses was considered negligible. Adequate acoustic treament of the inlet of this engine requires a sonic or near sonic choke to meet the noise limits. This type of acoustic treatment is directly scaleable and no additional performance penalties accrue with increase in size. Nacelle fan duct treatment is not affected by engine size, the primary noise treatment being contained in the wing/flap system. Primary exhaust treatment varies slightly with engine size but the variation has a negligible effect on engine installed performance.

5.2.3 AW Propulsion Performance Bookkeeping Methods

The airplane/propulsion bookkeeping procedures adopted for the AW lift concept are divided into terminal area operation and cruise operation. The terminal area operations are those flight operations in which the aircraft is in the augmented lift mode and the cruise operations are those operations for which the airplane/wing/nacelle are cleaned-up for climb and cruise flight.

Terminal Area Bookkeeping - The bookkeeping for the augmentor wing propulsion system performance for the terminal area is not amenable to conventional performance presentation practices. Since the airplane high lift aerodynamics are expressed as a function of a gross thrust coefficient, the propulsive forces are broken into gross thrust and propulsion system drag components. Installed propulsion system performance is presented as the following forces, each of which is corrected for the appropriate installation losses.

- Gross Thrust - For this concept, only the fan portion of the total installed thrust is utilized for the aerodynamic thrust coefficient. The basic engine data, as determined by the supplied computer program, has been degraded for inlet recovery loss, engine air bleed, power extraction, exhaust pressure losses (if applicable, includes all flow collector devices, pylon/wing ducting, nozzles, etc.), and nozzle coefficients.

- Propulsion System Drag - This item consists of the algebraic sum of the engine ram drag (degraded by the appropriate installation losses), the proper allowances for nacelle forebody, skin friction, afterbody boattail, base, and scrubbing drag, and the installed primary gross thrust. The primary gross thrust acts in the axial direction opposite to the direction of the nacelle drag and the ram drag. Since the primary thrust acts to negate the drag terms, proper accounting of these forces must be exercised to insure correct use of the drag characteristics to apply to this concept.

Cruise Bookkeeping - Conventional CTOL thrust/drag bookkeeping procedures have been employed for both climb and cruise data presentations in this study. Propulsion system net thrust and fuel flow values are presented on the basis of isolated nacelle forces acting at the bottom of the pylon. Pylon drag and wing/pylon/nacelle interference drag terms are included in the airplane drag. These nacelle forces include the basic performance of the engine, provided by the engine manufacturer, degraded for inlet recovery loss, engine air bleed, power extraction exhaust duct pressure loss due to friction, and nozzle coefficients. In addition to these internal losses, this engine net thrust is further degraded for external isolated nacelle drag including forebody, afterbody, skin friction, and scrubbing drag to result in the net propulsive forces acting at the bottom of the pylon but including the fan thrust exiting from the cruise nozzle at the aft end of the pylon.

The installed propulsion data that has been used for the augmentor wing airplane are presented in Figure 151 and were scaled by the vehicle sizing program to properly reflect the thrust level required for the selected baseline aircraft. Basic unit definitions and conversion factors applied to these installed data conform to both NASA SP-7012 and SAE ARP 681B documents. Nomenclature that has been used for Figure 151 is explained below:

F_s - Installed static total thrust. This value is the total uninstalled engine thrust degraded for inlet pressure recovery, fan duct pressure losses (including collector and all ducting to augmentor slot), primary duct pressure losses, slot and primary nozzle characteristics, all airbleed (ECS and aileron BLC) penalties, and power extractions.

F_{G_F} - Installed fan gross thrust. This value is the uninstalled fan gross thrust degraded by those elements of the above installation items that affect the fan stream. This thrust represents the energy available at the augmentor slot nozzle.

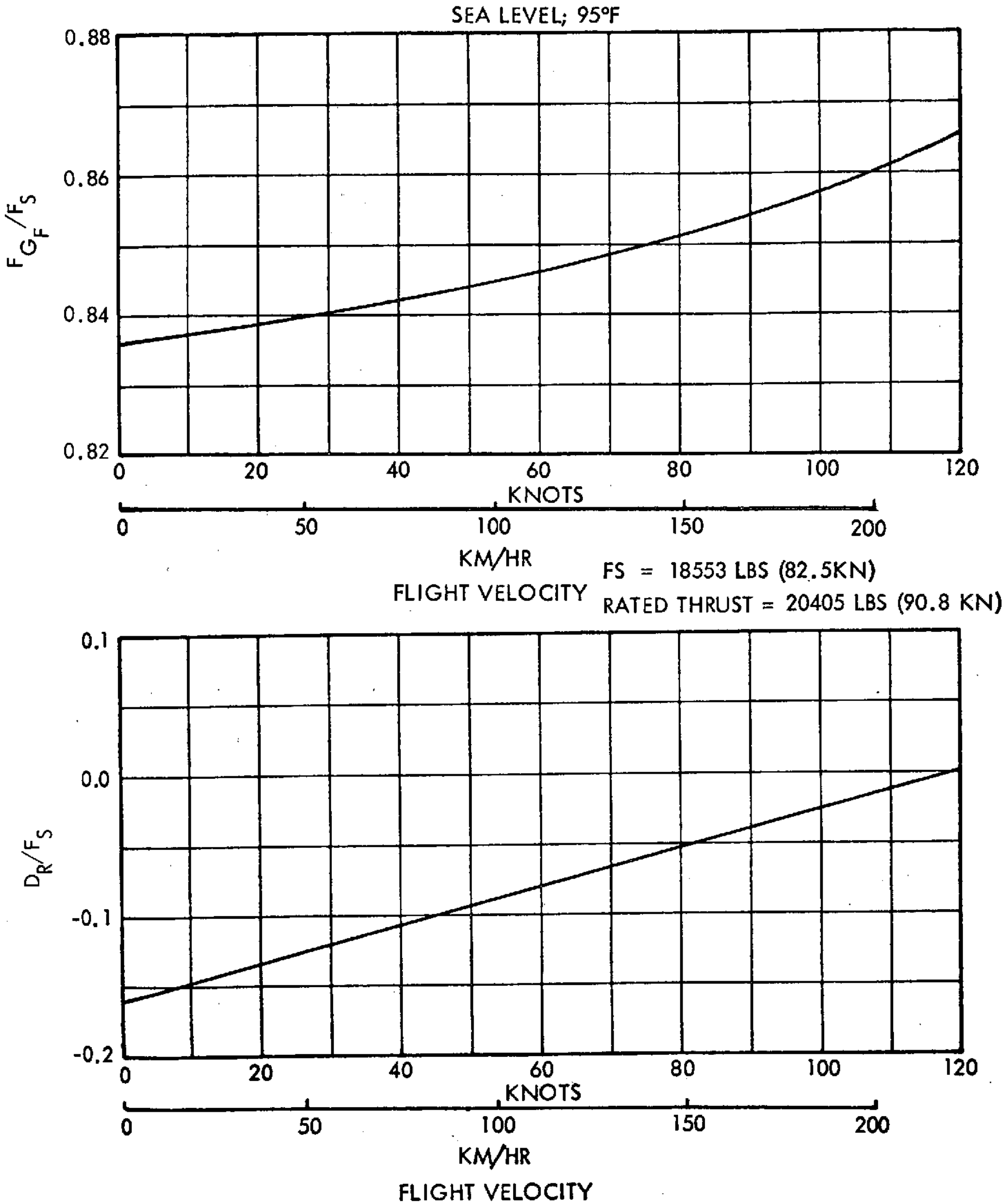


FIGURE 151: PD287-51 (SCALED) ENGINE TERMINAL AREA OPERATION

D_R - Propulsive drag term. This value is the sum of the installed ram drag plus the external nacelle aerodynamic drag minus the installed primary gross thrust.

5.2.4 AW Propulsion Installation

The typical underwing AW engine installation shown on Figure 152 has the unique requirement for a large duct to transmit the fan flow to the wing and in addition, provide for directing this flow to a cruise nozzle. The manner in which this is accomplished is largely a function of the engine configuration which includes a fan discharge collector with provision for a single engine/airframe duct interface on top of the engine. In this engine configuration, diversion of the fan flow between the terminal area mode (fan flow to the wing) and the cruise mode (fan flow to the cruise nozzle) is the total responsibility of the airframe company and is accomplished in the pylon with the cruise nozzle at the pylon trailing edge. In overwing nacelle installations, the engine proper is rotated through 180° from the position shown in Figure 152 but the underwing duct and cruise nozzle are retained. Hence, the primary nozzle exhausts over the wing, the collector is inverted but the wing entry arrangements are retained. The nacelle is appreciably deeper but the pylon is eliminated.

An alternative AW concept is the valveless or cruise-blowing system in which the fan thrust is discharged through the AW nozzles at all times including cruise. The concept has the benefit of elimination of valving and attendant duct losses but increases the losses in cruise thrust and SFC. Moreover, the propulsion system installation is not particularly enhanced by the replacement of the cruise nozzle at the pylon trailing edge by a necessarily blunt, high drag pylon trailing edge fairing. In either case, the nacelle configuration is dictated by the large diameter of the fan and fan discharge collector relative to the primary exhaust diameter. This results in a long afterbody having a large taper.

The inlet is of conventional configuration and is not constrained by any requirements for acoustic treatment since the sonic guide vanes provide suppression of fan noise. The nacelle location and pylon configuration are largely dictated by the ducting requirements

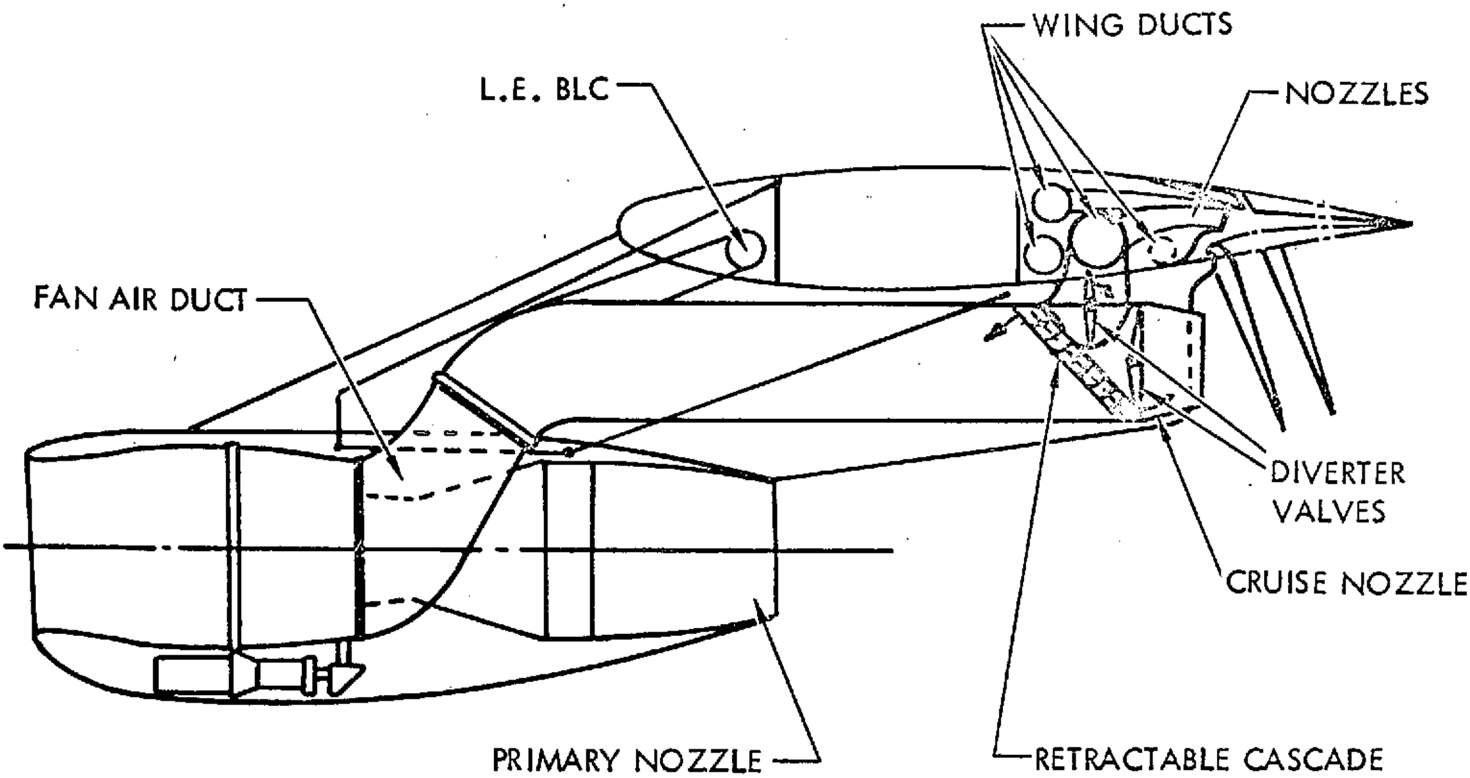


FIGURE 152: TYPICAL AW POWER PLANT INSTALLATION

T.14-1 **TAKEOFF FLAPS**

δ_f	25.00000						
C_T	.00000	.77000	1.47000	3.00000			
α	-5.00000	.00000	5.00000	10.00000	15.00000	20.00000	25.00000
C_L	.17760	.59662	.99045	1.37868	1.71519	1.98644	2.17743
	1.14142	1.75233	2.35447	2.96047	3.52261	4.02706	4.45802
	1.47267	2.17540	2.86650	3.57933	4.18750	4.79724	5.38039
	1.47458	2.47848	3.42773	4.29004	5.05452	5.66433	6.16816
C_X	-.13088	-.13388	-.16605	-.21233	-.26751	-.34818	-.41648
	.59387	.51635	.40641	.24633	.05574	-.15758	-.38963
	1.28374	1.19565	1.04811	.85222	.61941	.35292	.05696
	2.35418	2.31200	2.19782	2.01786	1.82254	1.59430	1.37172

T.14-3 **LANDING FLAPS**

δ_f	70.30000						
C_T	.00000	.40000	.77000	1.10000	1.47000	3.00000	
α	-5.00000	.00000	5.00000	10.00000	15.00000	20.00000	25.00000
C_L	.61142	.98130	1.26070	1.54772	1.80875	2.06502	2.23896
	2.26867	2.68925	3.09865	3.49275	3.83215	4.07495	4.12065
	3.39407	3.91925	4.39638	4.87740	5.23690	5.46413	5.45910
	4.03875	4.53008	5.07315	5.51784	5.98534	6.21349	6.27481
	4.59300	5.10660	5.65108	6.14933	6.62581	6.90076	6.968[illegible]
	4.75100	5.75775	6.65548	7.36541	7.90203	8.27716	8.37605
C_X	-.26437	-.27809	-.31385	-.34957	-.39101	-.48402	-.58290
	-.23648	-.35896	-.48310	-.63760	-.79011	-.95147	-1.09762
	-.20976	-.42360	-.64269	-.87500	-1.11587	-1.33683	-1.54601
	-.16246	-.41674	-.70726	-1.0[illegible]316	-1.29736	-1.59153	-1.87196
	-.07479	-.37047	-.71246	-1.06943	-1.45832	-1.83[illegible]19	-2.16892
	.13287	-.31745	-.76982	-1.21792	-1.69721	-2.18091	-2.61918

TABLE XIV: AW BASIC AERO DATA

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and interference drag considerations. There has been recent evidence that sonic guide vanes on the engine may not adequately meet the noise and performance criteria. The alternatives appear to be a further performance penalty associated with vanes adequate to meet the noise criteria, further inlet acoustic treatment or abandonment of the guide vanes in lieu of a sonic or near sonic inlet. The latter option would entail either a variable geometry inlet or a prohibitive cruise performance penalty if the approach power noise criteria are to be met. All alternatives result in further performance degradations and/or weight penalties. Since the existing data including the sonic guide vanes are optimistic in any event, it was elected to use the data without further degradation.

Nacelle Location - The basic spanwise positions for the nacelles on the AW airplane have been selected to provide good distribution of the fan airflow into the wing and flap ducting with moderate pressure loss, to provide acceptable interference drag levels and allow compatible structural characteristics. These considerations present conflicting requirements, particularly when an upper limit of 15 percent is imposed on duct total pressure loss. A minimum separation of nacelles from each other and from the fuselage of one nacelle diameter is desired from the standpoint of interference drag but this location of the outboard engine may either restrict the wing ducting or impose structural problems due to aft wing spar location having to be too far forward. These problems are somewhat relieved by a wing of constant chord from the root to the outboard engine location, as discussed in Section 5.4. The outboard nacelle was ultimately located one nacelle diameter from the inboard engine by accepting some compromises on aft wing spar location and accepting overwing nacelles for the lower aspect ratio wings. Vertical and horizontal locations are dictated by the pylon structure and internal ducting requirements with ground clearance as a further consideration.

Nacelle Inlet/Forebody Design - The inlet/forebody for this application was selected in general conformance with the considerations discussed for the OTW/IBF configuration in Section 4.2.4. The use of sonic inlet guide vanes to suppress the fan inlet noise eliminates the requirement for inlet wall or splitter ring acoustic treatment. The inlet was therefore configured by aerodynamic considerations only. The performance characteristics of this inlet are conventional since the performance losses of the sonic inlet guide vanes are included in the performance of the basic engine. If, as was noted earlier, the sonic inlet guide vanes should prove inadequate to meet the noise criteria, additional performance or weight penalties would accrue from any of the alternatives. The data as used are therefore optimistic.

Exhaust Data - The engine for the AW airplane includes a collector for the fan exhaust flow and provides an interface with airframe hardware in the form of an elliptical duct attachment point at the top of the pylon. This engine configuration dictates a single duct arrangement through the pylon with a valve mounted in the pylon to divert the fan flow into the wing for terminal area operation or to a cruise nozzle located at the pylon trailing edge. An alternate design could be configured for a conventional annular fan exhaust for cruise with blocker doors and a shutoff valve in the pylon duct to divert the flow to the wing. Only a detailed trade study could determine the optimum of these two systems. The configuration chosen provides a viable base for airplane study with reasonable performance penalties. The configuration does not include any acoustic treatment in the engine/wing ducting since target noise levels are achievable through multi-element nozzles and acoustic treatment in the augmentor flaps.

The high fan pressure ratio of this engine precludes achieving a noise level in reversed thrust which is consistent with the noise criteria if any of the more conventional reverser configurations are adopted. A number of reverser configurations have been considered which include ducting fan flow forward through the pylon leading edge, mounting cascades on the side of the pylon, discharging the fan flow through the upper wing surface, and closing the augmentor flap exit, thereby diverting the fan flow out of the forward opening of the flap. Of these, only the latter configuration would appear to offer a significant, albeit unknown, reduction of reversed thrust noise level at some reduction in reversed thrust performance but with excellent spoiling of wing lift. Inasmuch as the reversers are not required for the design point airplane to meet the target field length, the reverser has not been defined and has been deleted from the specific configuration. The flap reverser configuration could be exercised further if the AW configuration is considered attractive and reversers should prove to be definitely desirable. To be consistent with other concepts and to avoid being overly optimistic in the airplane study, the weight of an engine mounted cascade reverser has been carried in the airplane performance analysis and should be basically adequate to cover the weight of any selected reverser configuration.

The primary exhaust system is a conventional convergent nozzle with moderate acoustic treatment for turbine noise. The turbine noise treatment delineated by the engine manufacturer was confirmed by Lockheed and used without modification. The primary exhaust thrust reverser of the engine manufacturers configuration has been deleted along with the fan thrust reverser. Iteration of the engine performance and match characteristics with DDA led to a requirement for a variable area primary nozzle as a means of improving the cruise SFC by five percent. The SFC improvement was incorporated in the installed engine performance data. The weight of the primary thrust reverser, not previously deleted from the engine weight, was considered to represent the weight increment for the variable area nozzle.

Nacelle Afterbody - The selection of the nacelle afterbody is largely dictated by the basic engine configuration which necessitates a long afterbody. The afterbody boattail angle was held to 14° with a circular arc configuration with modification dictated by the LP turbine case diameter and primary nozzle exit in order to reduce nacelle length. This configuration is consistent with current practice.

Noise Suppression Components - The acoustic suppression of inlet noise on the AW engine as provided by DDA is accomplished by engine furnished sonic inlet guide vanes. These vanes are controlled by engine furnished actuators and sequencing components. The performance penalties associated with this equipment is included in the basic engine data. Lockheed concurs that this is a feasible system for inlet noise suppression on this engine and offers advantages over alternative means of sonic inlet noise suppression if adequate attenuation can be achieved with reasonable loss. As noted earlier, all alternatives increase the loss so the assumption of this system results in optimistic performance. Lockheed also concurs with the DDA treatment for turbine noise in the primary exhaust duct and the performance penalties associated therewith. Specific treatment of the fan exhaust noise is all contained in the wing/flap system.

5.3 AW AERODYNAMIC DATA

Both the orthodox and load-compressor AW vehicles have a similar flap configuration to that adopted in the work reported in NASA CR 114612. Hence, no changes have been made to either the low speed or the high speed data base previously used, and the general methodology outlined in Section 4.3 for the OTW-IBF vehicles is directly applicable to AW.

The base set of low speed experimental data which are taken from NASA TMX-62028 have been trimmed and the ram drag of the primary air removed. Neither scale effect corrections to ram drag nor corrections for configurational differences have been made. Low speed data for typical takeoff and landing flap settings at a representative aspect ratio of 6.5 are presented in Table XIV. The direction of 10% of the fan air to wing leading edge blowing 5% to aileron BLC and 85% to the augmentor flap per se with similar pressure recoveries in each component is assumed and C_T is referred to the overall gross nozzle thrust in these data. Comparison of the above NASA test data with later Boeing data developed in the course of the extensive studies which are summarized in NASA CR-114283 shows close correspondence despite the use of a slit nozzle in NASA tests and multiple nozzle array (with higher augmentation ratios) and leading edge blowing in the Boeing data. From this, it would appear that the increased augmentation ratio of the latter arrangement has been compensated for by the higher proportional thrust split to the flap in the former case.

For the purposes of parametric AW vehicle optimization in this study, the effects of geometrical changes to the aspect ratio, sweep and taper ratio have been assessed taking the following into account:

- o Increase of the direct thrust lift component with reduction in aspect ratio because of the reduced lift curve slope and thus higher incidence at a given lift coefficient.

- Reduction of the circulation lift component with reduction in aspect ratio because of the effects of trailing vortex sheet deflection on attainable lift.

- Reduction of the direct thrust C_X component with reduction in aspect ratio because of reduced lift curve slope.

- Increase of the circulation induced-drag C_X component (-) with reduction in aspect ratio arising from the reduced lift curve slope with account taken of the trailing vortex sheet deflection effects.

No sweep penalty on C_{LMAX} has been included on the argument that, for short range STOL vehicles cruising at modest lift coefficients, the wing twist distribution can be designed to maximize C_{LMAX} rather than to ensure a "near-elliptical" cruise lift distribution. By this assumption the twist distribution compensates for the increase in peak local lift coefficients with sweep on a plane wing and a sensibly constant C_{LMAX} can be achieved over the range of sweep angles of interest. The distortion of the cruise lift distribution from the elliptical can be relatively large without significantly increasing induced drag (which is, itself, of "secondary" significance for a short range vehicle cruising well above minimum drag speed (V_{md}) because of the non-optimum wing area required for STOL performance).

Consideration has been given to the possible effects of a 'valveless' or 'cruise blowing' augmentor wing system on wing thickness as limited by drag rise consideration. Examination of reference 29 a Boeing report on high speed tests of the valveless system, does reveal a small beneficial effect of the valveless system on allowable airfoil section thickness. Data in this report also reveal, however, that the exhaust nozzles associated with the valveless concept incur a large drag penalty of 20 to 30 counts compared with a system having valves and a conventional pylon/nacelle arrangement. This penalty may be expected to outweigh any total system benefits arising from the small thickness ratio change alone which are briefly discussed in para. 5.4.5

As a by-product of high speed tests conducted to check OTW nacelle concepts, data were obtained on a configuration which approximates to one of the AW nacelle arrangements. The model tested is that which was already shown in Figure 40. Results indicate that this arrangement is superior to the valveless concept, but inferior to the hybrid augmentor wing concept with mechanical flap type cruise engines and load compressors for AW flow.

5.4 BASELINE MISSION AW VEHICLES

Parametric studies have been accomplished to identify the preferred configuration options which minimize the DOC of the AW. The factors affecting DOC which have been considered include:

- o Number of engines
- o AW ducting configuration
- o Target pressure loss in the AW duct system
- o Wing aspect ratio and sweep
- o Wing-nacelle-ducting integration (geometry)
- o Level of airfoil technology (drag divergence)

The tradeoff between duct loss and augmentation ratio in varying the proportional space allocated to ducting and flap aft of the wing rear beam is beyond the scope of this study but has been evaluated in the "Design Integration and Noise Studies for Jet STOL Aircraft" conducted by Boeing under NASA contract NAS 2-6344 and summarized in reference 32. The rear beam location and flap chord selected by Boeing in Task V of that study now correspond closely to the Lockheed study configuration.

The conclusions reached in these studies have been implemented in the subsequent sizing of the "optimized" augmentor wing vehicles for the design mission

5.4.1 Optimum Number of Engines

Initial two-and four-engine configurations were derived to provide the point of departure for optimization studies. These aircraft were based upon the preferred fan pressure ratio engines (FPR - 3.0) identified in reference 2 which are completely dependent upon the noise attenuation of the augmentor to achieve tenable noise levels. Hence, a three-engine configuration would require either a much lower fan pressure ratio for a (non-augmented) tail mounted engine or a centerline overwing (augmented) installation with an extensive pylon raising the cruise nozzle well clear of the fuselage. In view of the doubtful practicality of either approach, three-engine arrangements have not received further consideration.

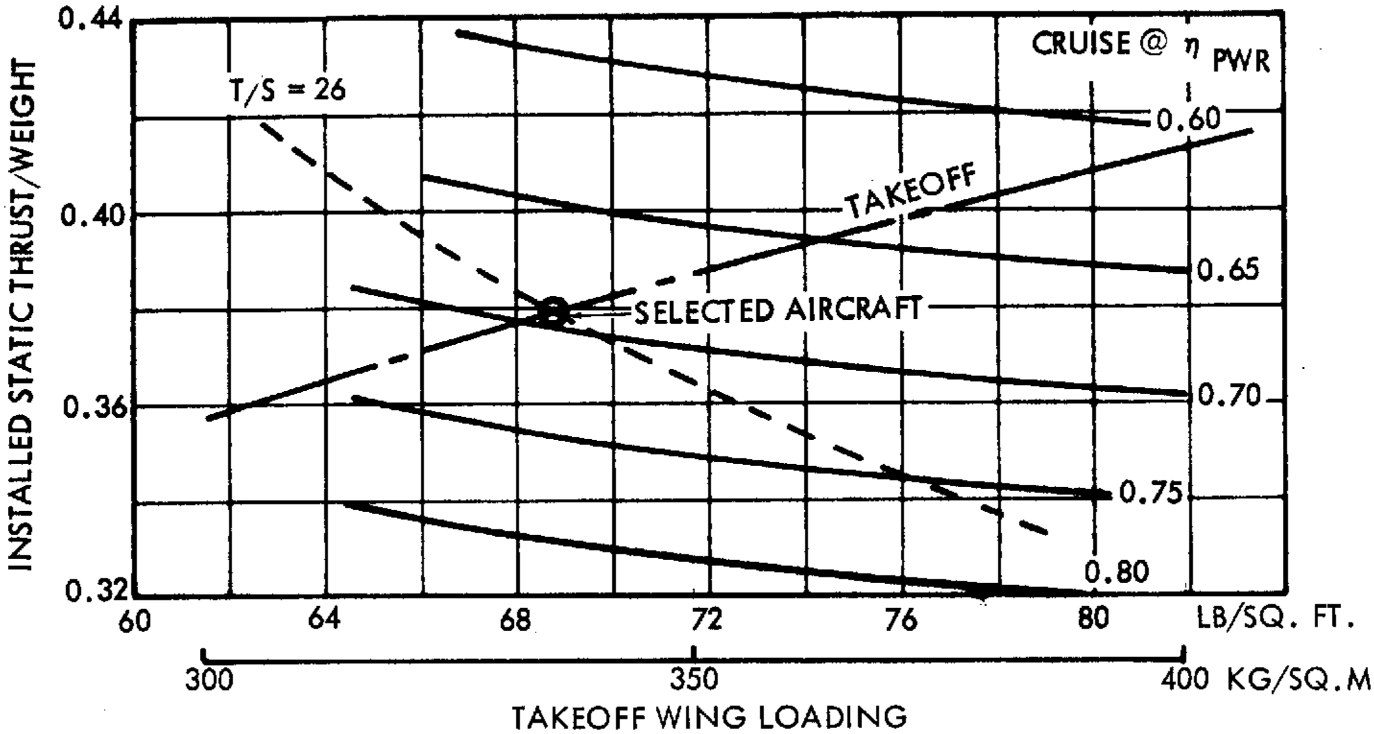
Figures 153 and 154 present the takeoff thrust-weight, wing loading and DOC relationships for parametric two- and four-engine aircraft, respectively. The individual curves shown in these figures indicate the thrust and wing loadings required to comply with:

- The cruise requirements, i.e. 926 Km. (500 N.Mi.) stage; M = 0.8 @ 9140m. (30,000 ft.) at various power settings (η_{PWR})
- The 910m. (3000 ft.) field length requirement
- Installed thrust limits imposed by the target 85% recovery in the AW duct system.

These data are predicated upon wing aspect ratios of 7.0 and 6.5 for the two- and four-engine vehicles respectively and are associated with a taper ratio of 0.4. The AW duct system pressure losses estimated for the 610m. (2000 ft.) field, four-engine AW-2S configuration in reference 2 have been assumed to be representative of both engine arrangements and provisional T/S limits of 26.0 and 32.6 for the two- and four-engine vehicles have been set accordingly. These limits correspond to approximately 10% higher T/S values than direct application of reference 2 data would indicate in anticipation of the improvements expected to accrue from improved matching of the planform taper distribution to the duct volumetric requirements and appropriate relocation of the nacelles as later described in paragraph 5.4.4. (Comparisons with the T/S data for the Boeing four-engine vehicle described in NASA CR-114534 under Task V update, indicate Lockheed figures to be approximately 5% higher when adjusted for the differences in engine fan pressure ratio, aspect ratio, sweep and airfoil thickness distribution).

Figures 153 and 154 indicates that both the two- and four-engine vehicles are essentially sized by the takeoff requirement in conjunction with their T/S limits. However, both constraints are significantly more severe for the two-engine vehicle and restrict it to a much lower wing loading and cruise power setting than the four-engine vehicle. Hence, both the attainable DOC and ride quality of the two-engine vehicle are markedly inferior to those of the four-engine aircraft. It should be noted that even in the absence of any T/S constraint for the two-engine vehicle, the inferior field performance alone would preclude the two-engine vehicle from competing with the four-engine arrangement.

M = 0.8, 9140M (30,000 FT) CRUISE ALTITUDE, 910M (3000 FT) FIELD LENGTH, FPR = 3.0



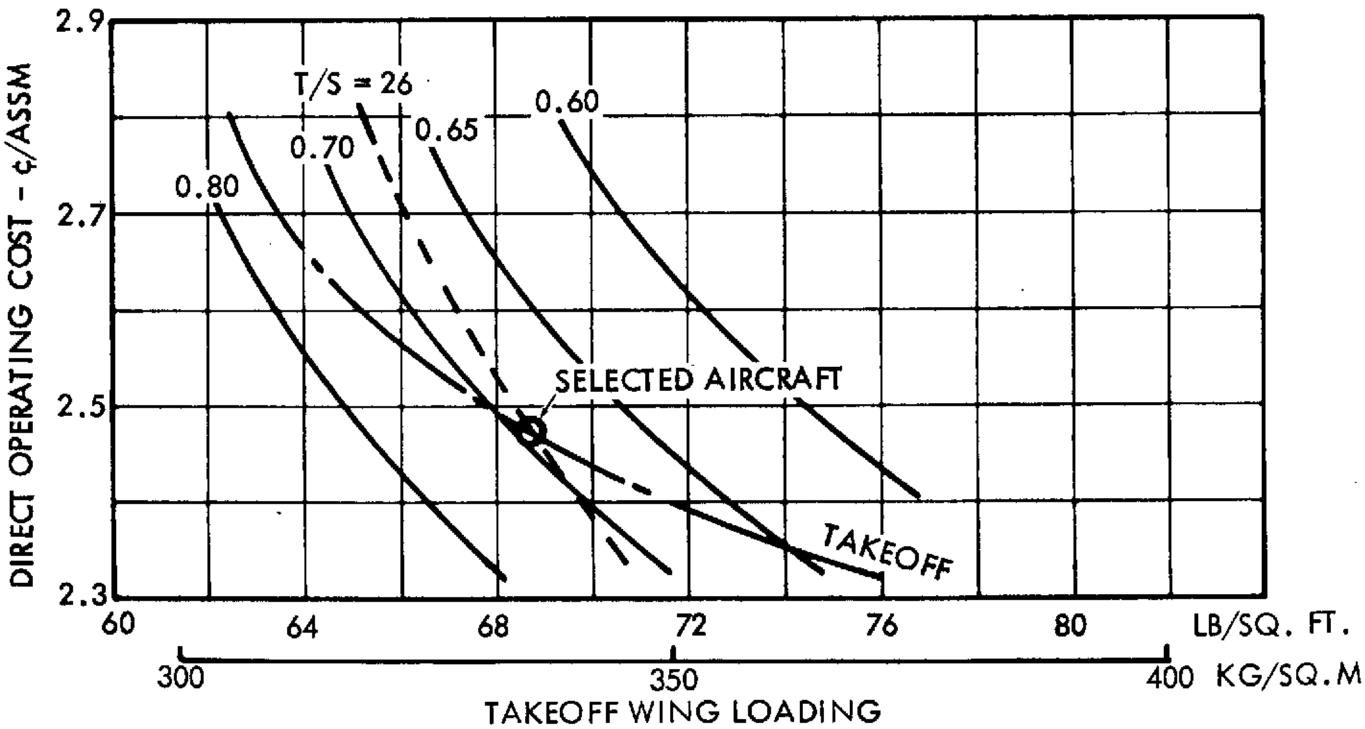
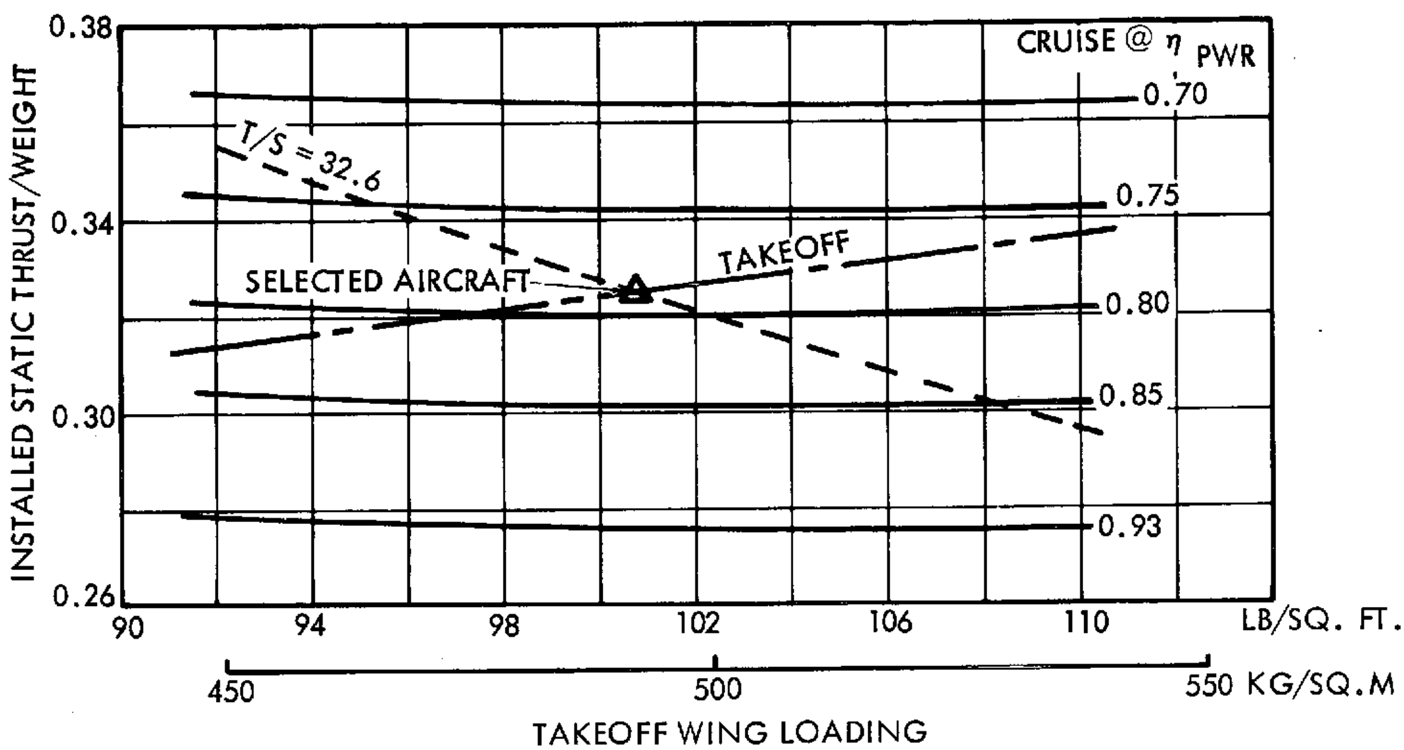


FIGURE 153: INITIAL 2-ENGINE VEHICLE SELECTION

M = 0.8, 9140M (30,000 FT) CRUISE ALTITUDE, 910M (3000 FT) FIELD LENGTH, FPR = 3.0



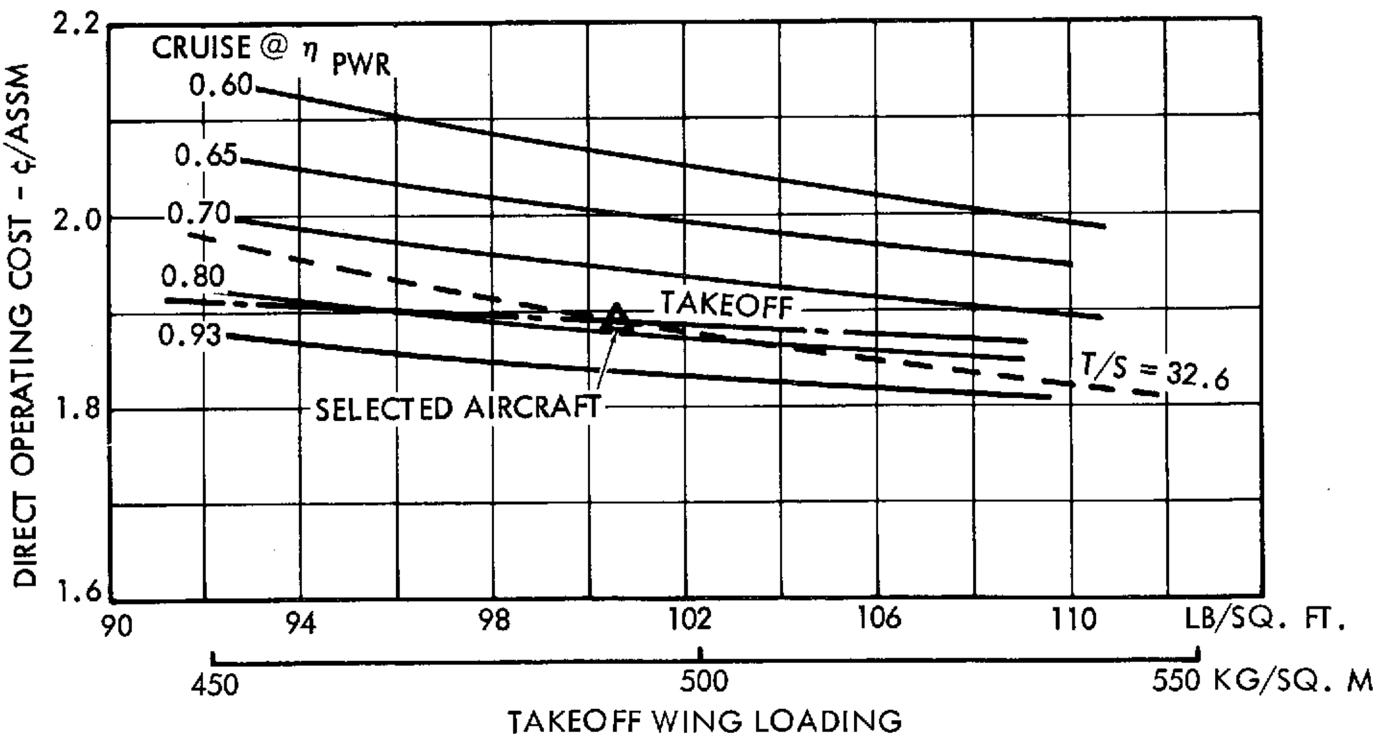


FIGURE 154: INITIAL 4-ENGINE VEHICLE SELECTION

This point is further illustrated in Figure 155 in which the two- and four-engine T/W and DOC curves for cruise-sized vehicles have been plotted on a common W/S basis for power settings (η_{PWR}) of 0.7, 0.8, and 1.0. It is noted that at any similar wing loading and power setting the two-engine cruise sized vehicle would be superior to the four-engine arrangement were it not for the other design criteria.

Although a clear preference for the four-engine arrangement has been indicated by these data, both configurations have been included in the subsequent optimization process to establish their differences more positively.

5.4.2 Optimum Flow Split

It may be postulated that the function of the LE BLC system in delaying the stalling incidence of the wing to approximately 25° can be equally well performed by a leading edge slat. Hence, the lift capabilities of the wing for a given augmentor thrust but different leading edge devices may be expected to remain sensibly constant and this hypothesis tends to be supported by the close similarity between Boeing and NASA tunnel AW lift data when correlated as a function of C_J and and the differences in leading edge treatment and AW nozzle augmentation ratios are taken into account. On this argument, the effects of varying the thrust split between augmentor and BLC systems for both two and four engine vehicles has been estimated to amend the takeoff and T/S design constraints as illustrated in Figures 156 and 157, respectively.

In the interests of conservatism, the diversion of additional flow to the leading edge system has not been assumed to contribute to a higher $C_{L\ MAX}$ (which is thus dependent upon the augmentor flow alone). Therefore, because of the additional scrubbing and other thrust losses in the leading edge flow, a higher overall installed (nozzle) thrust

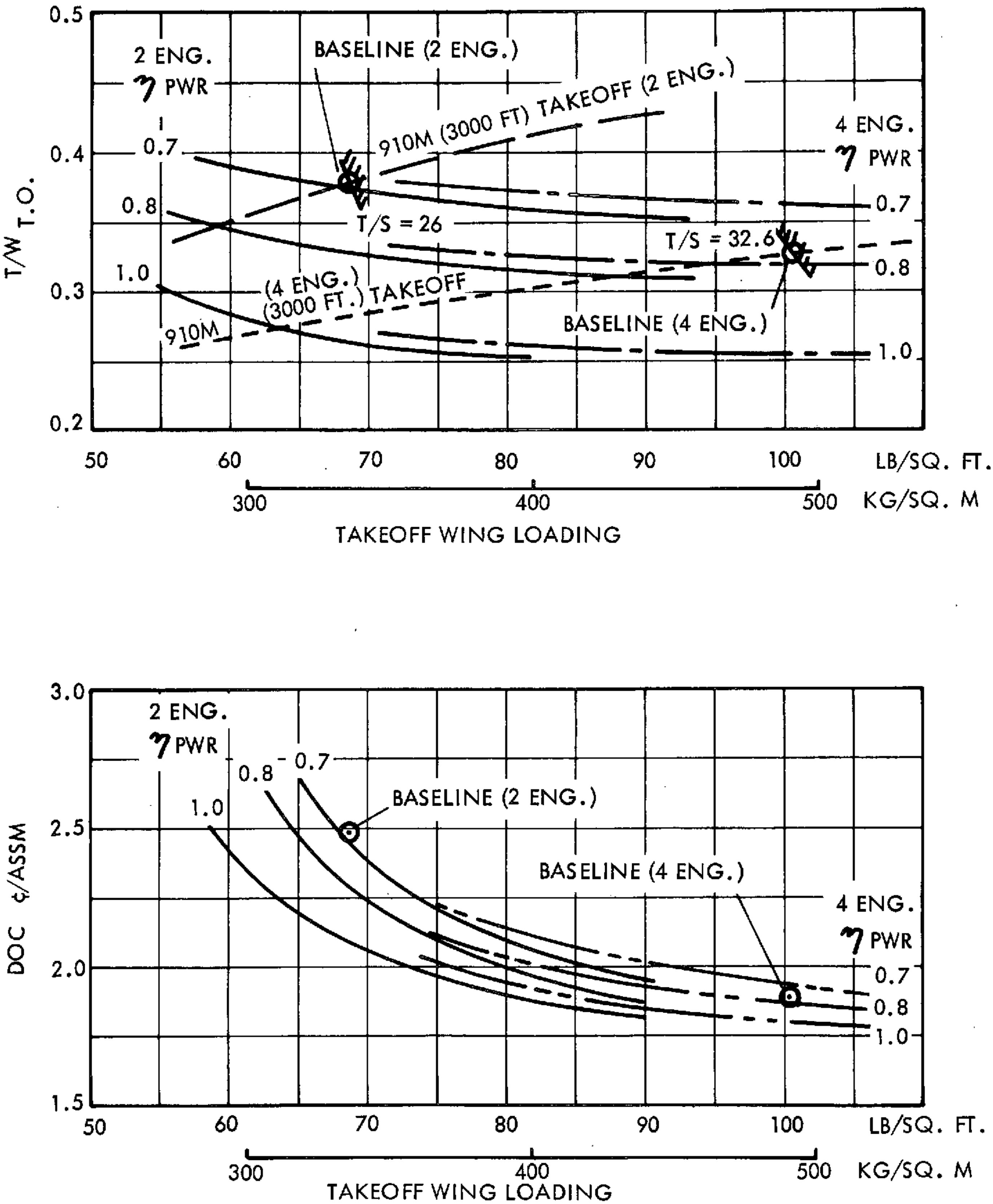
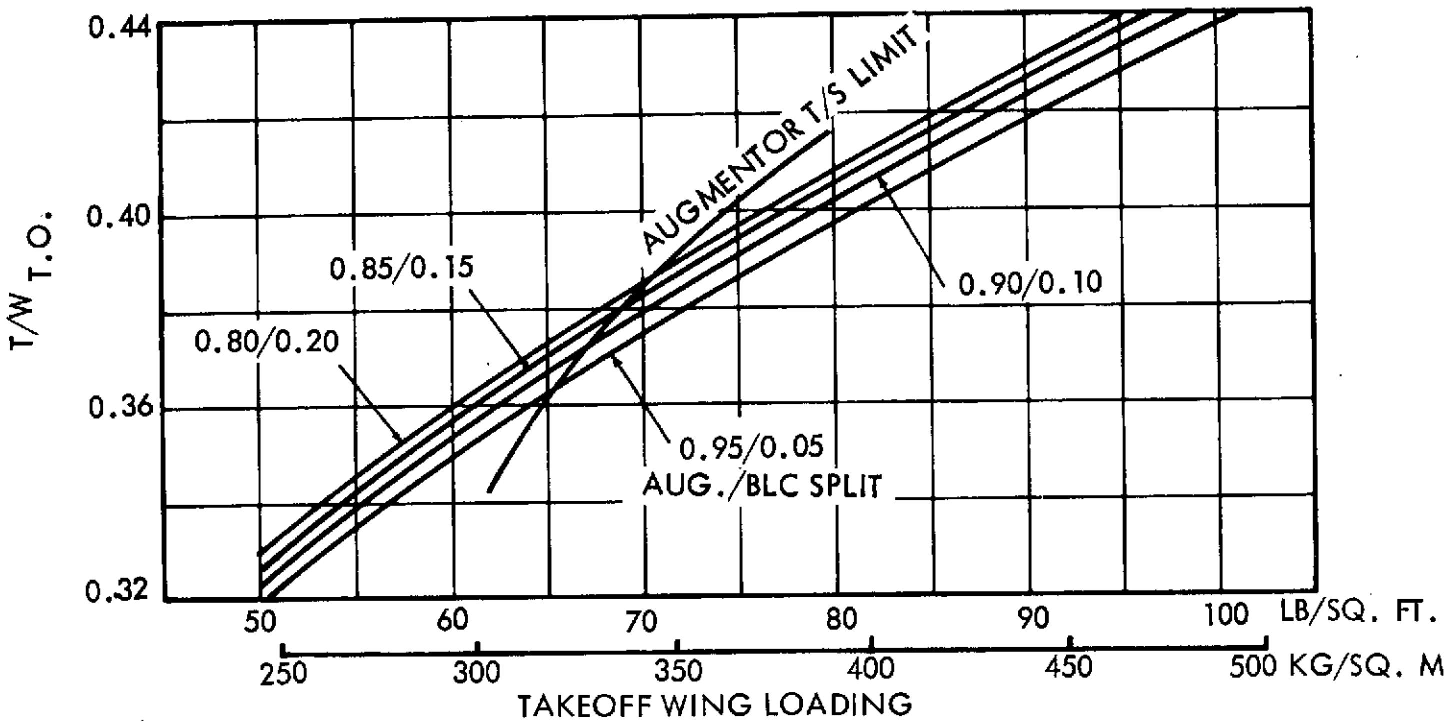


FIGURE 155: COMPARISON OF TWO- AND FOUR-ENGINE AW AIRCRAFT



910M (3000 FT.) TAKEOFF DISTANCE: AR = 7.0: 30° SWEEP

EFFECT OF THRUST SPLIT ON DOC AND WING LOADING

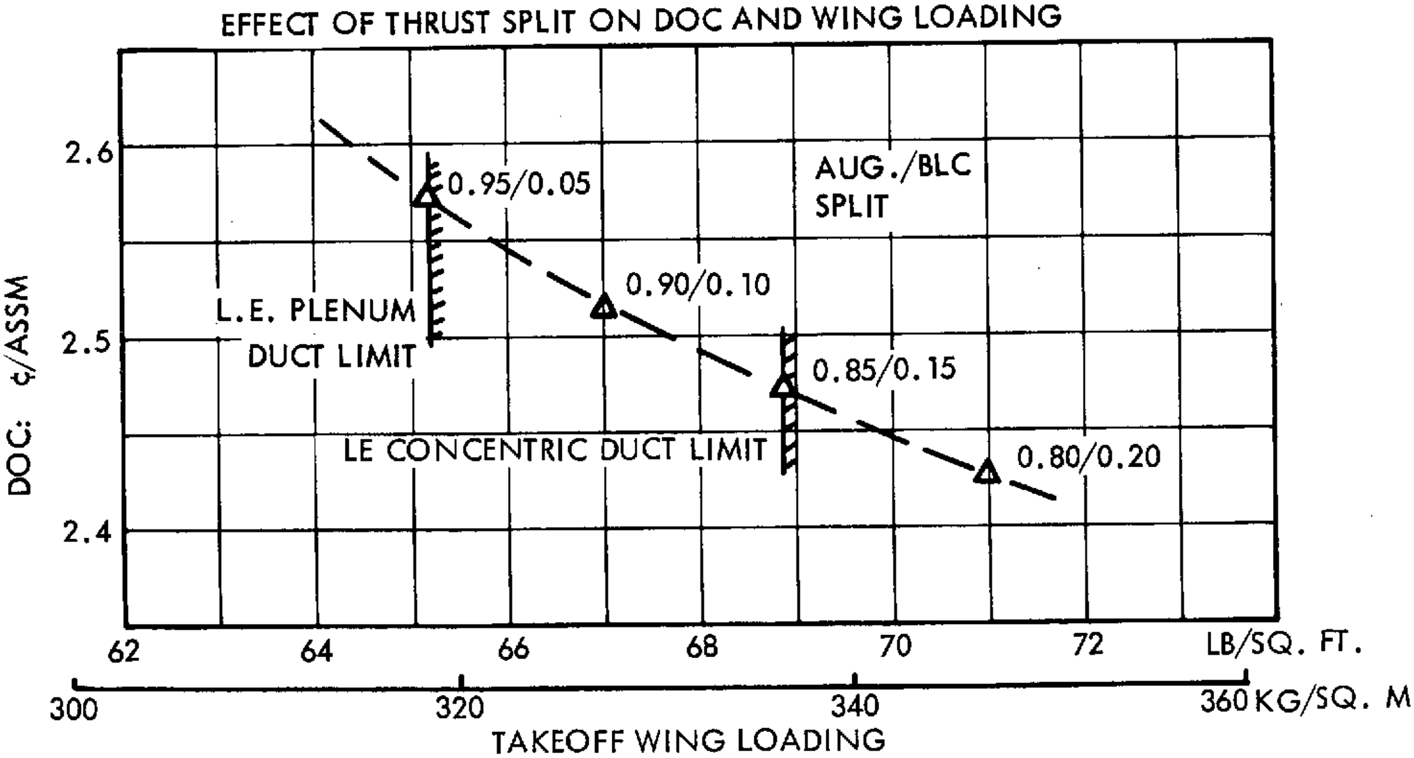
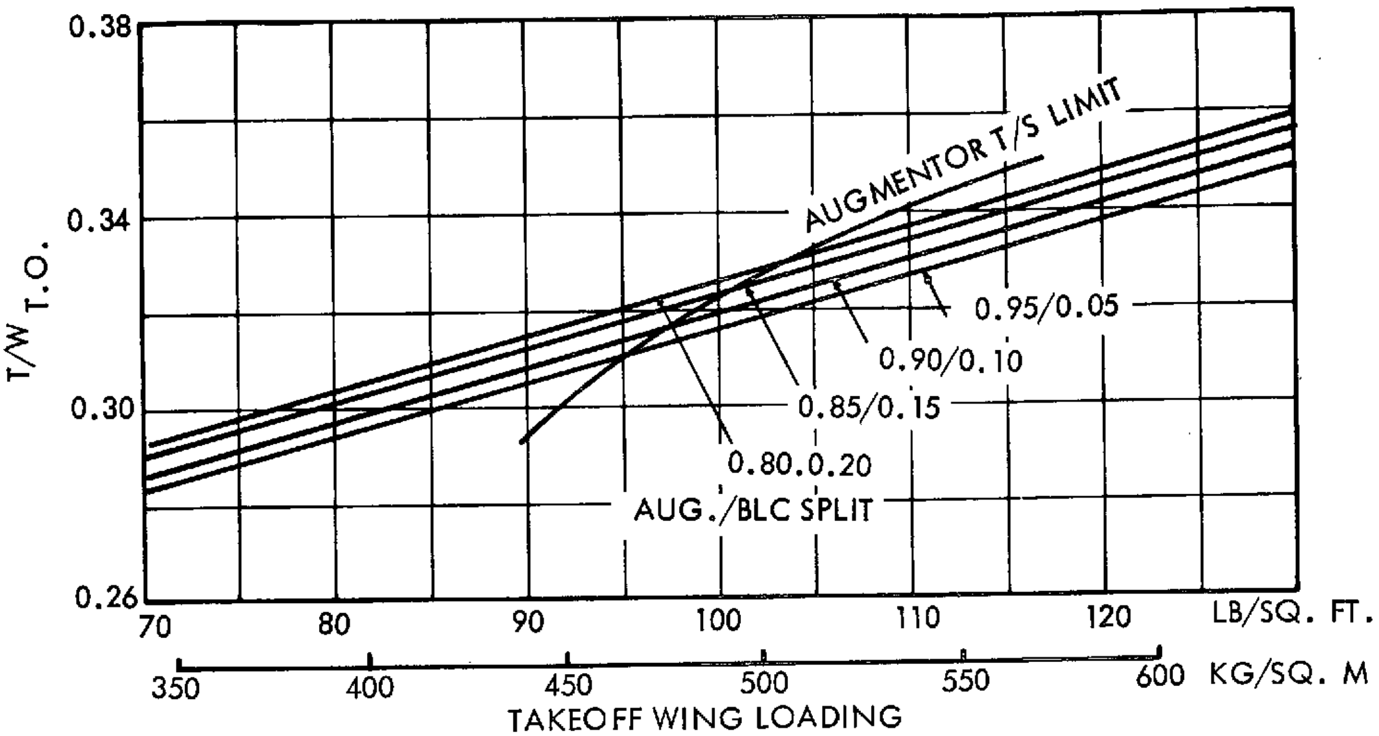


FIGURE 156: OPTIMUM AUGMENTOR/BLC THRUST SPLIT (2-ENGINE)



910M (3000 FT.) TAKEOFF DISTANCE: AR = 6.5: 30° SWEEP

EFFECT OF THRUST SPLIT ON DOC AND WING LOADING

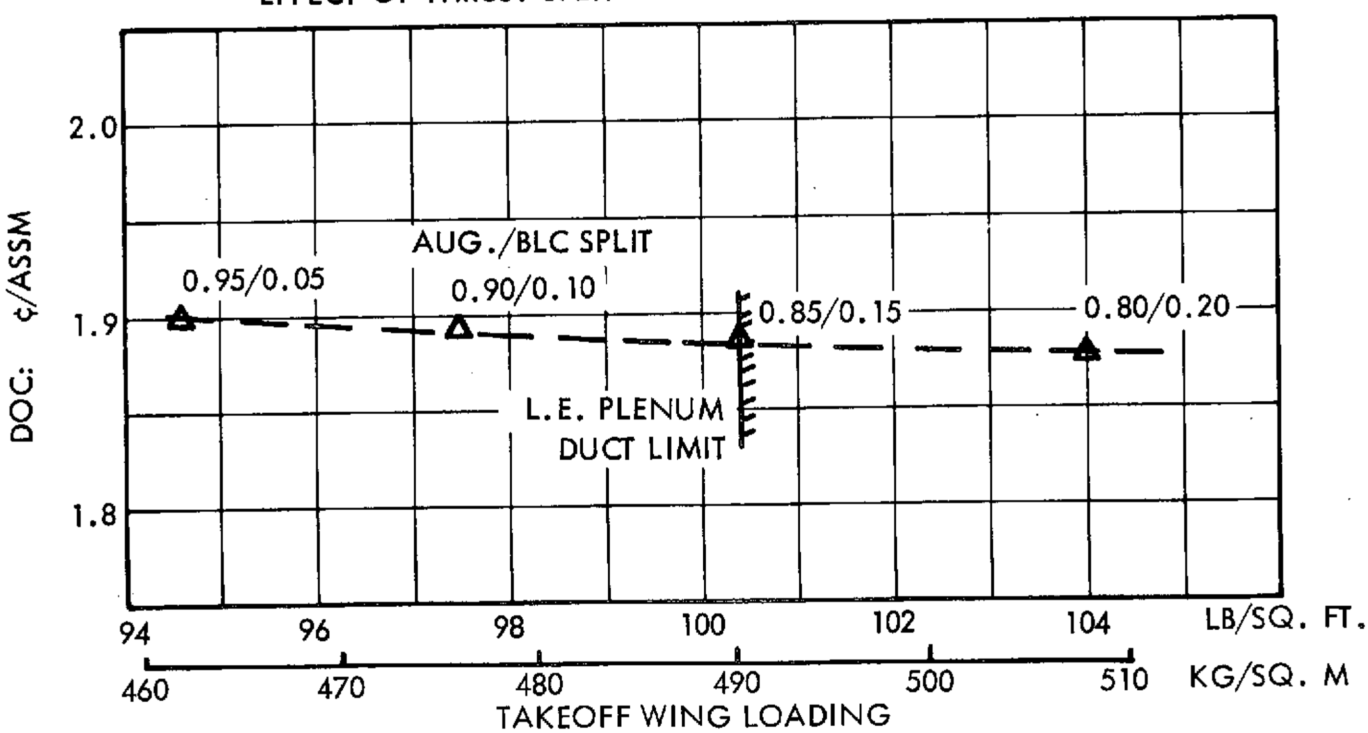


FIGURE 157: OPTIMUM AUGMENTOR/BLC THRUST SPLIT (4 ENGINE)

is required with increasing augmentor/BLC mass flow split for a given field length. However, this may be offset by the relaxed T/S limit indicated in the upper charts of Figures 156 and 157 since a greater total wing flow can be accepted in a wing of given size.

From these figures it will be noted that in either case the net effect of using LE BLC is to increase the attainable wing loading, improve ride quality and reduce DOC because of the higher T/S permitted. In the use of the twin engine vehicle, it would pay to pass as much air through the wing as possible (beyond the augmentor capacity alone) provided that the additional noise could be attenuated adequately. Little benefit for thrust splits beyond 85:15 is indicated for the four engine vehicle.

The restricted space available in the wing leading edge generally necessitates the use of a plenum system for the BLC flow to the wing leading edge and aileron. In these circumstances, engine-out considerations limit the BLC flow to 15% of the fan flow in the four-engine arrangement and to only 5% in the two-engine arrangement. The allowable flow split between the augmentor and BLC system would then depend upon the number of engines, as follows:

	4-Engine	2-Engine
AW Proportion of fan flow	0.85	0.95
L.E. BLC Proportion of fan flow	0.10	-
Aileron BLC Proportion of fan flow	0.05	0.05
Total	1.00	1.00

Hence, a leading edge plenum duct would imply a reduction of 10.5% in the T/S limits ascribed to the two-engine airplane which has not been recognized in sizing the initial vehicle. However, it has been established that at the relatively low wing loadings in prospect for the two engine airplane, concentric independent ducts may be accommodated of sufficient size to accept 15% of the fan air flow (to which four engine vehicles are also limited) without excessive pressure losses.

5.4.3 Optimum AW Duct Pressure Recovery

The preferred target level for the recovery of fan (total) pressure at the AW nozzles have been derived for both the two- and four-engine baseline vehicles. This analysis has been based upon the estimates of incompressible AW system losses for the 610m (2000 ft.) field, four-engine AW-2S point design which were made in reference 2. These estimates were derived from a summation of individual component friction and other losses occurring at valves, duct bends, contractions and expansions, etc. added to duct frictional losses and recognizing the variation of local flow velocity throughout the length of the system. Since the capabilities of the AW-2S vehicles are dependent upon the attainable T/S, the minimum losses which might be achieved by intensive development of an actual system have been assumed throughout.

For each level of design fan pressure recovery (η_{FP}) at the average nozzle exit, the allowable mass flow in a system with the loss characteristics has been estimated with appropriate allowance made for the effects of compressibility and the effect of system losses upon duct Mach number. Figure 158 presents average nozzle pressure ratio as a function of fan pressure recovery and the corresponding thrust recovery factors for fan gross thrust (η_{FG}), static net thrust (η_{FN}) and overall propulsion installation loss (static) referred to sea-level, standard day, rated thrust (η_i). Figure 159 presents the corresponding system Mach No. and compressible loss coefficient ($\Delta P/q$) for selected stations as a function of fan pressure recovery. These estimates are predicated upon the maintenance of subcritical and (generally) attached flow throughout the system and will be invalidated by any shock induced separation which may occur at high Mach No. in various components. The need to design duct systems to very high Mach No. has not arisen elsewhere in aircraft practice and consequently there is a lack of reliable test data for such effects. Accordingly, arbitrary limits for the Mach No. at which divergent pressure losses may be expected to arise in duct bends and vaned nozzle entries, etc. have been taken as 0.5M and 0.65M respectively. These cut off values limit the design fan pressure recovery as indicated in Figure 159.

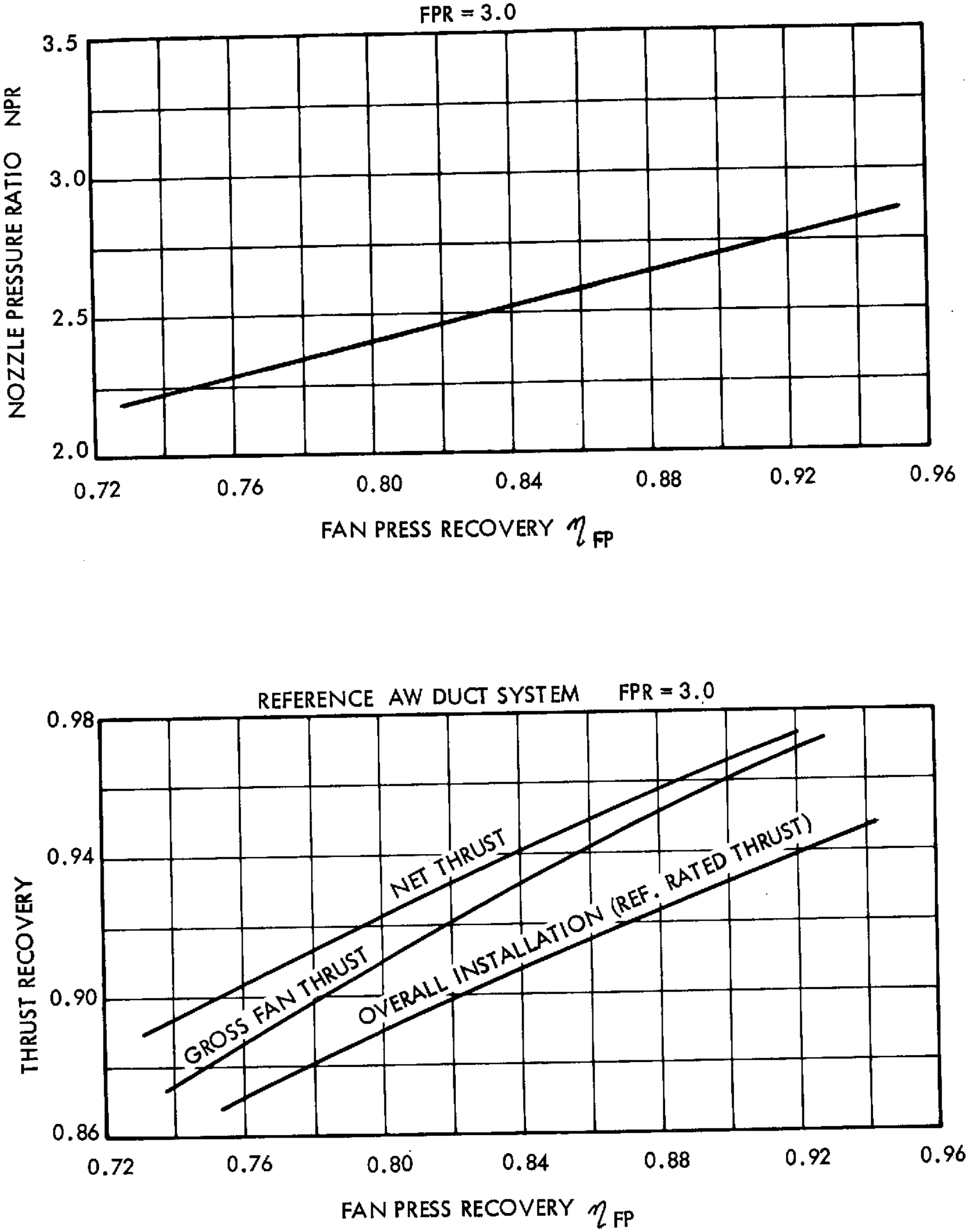
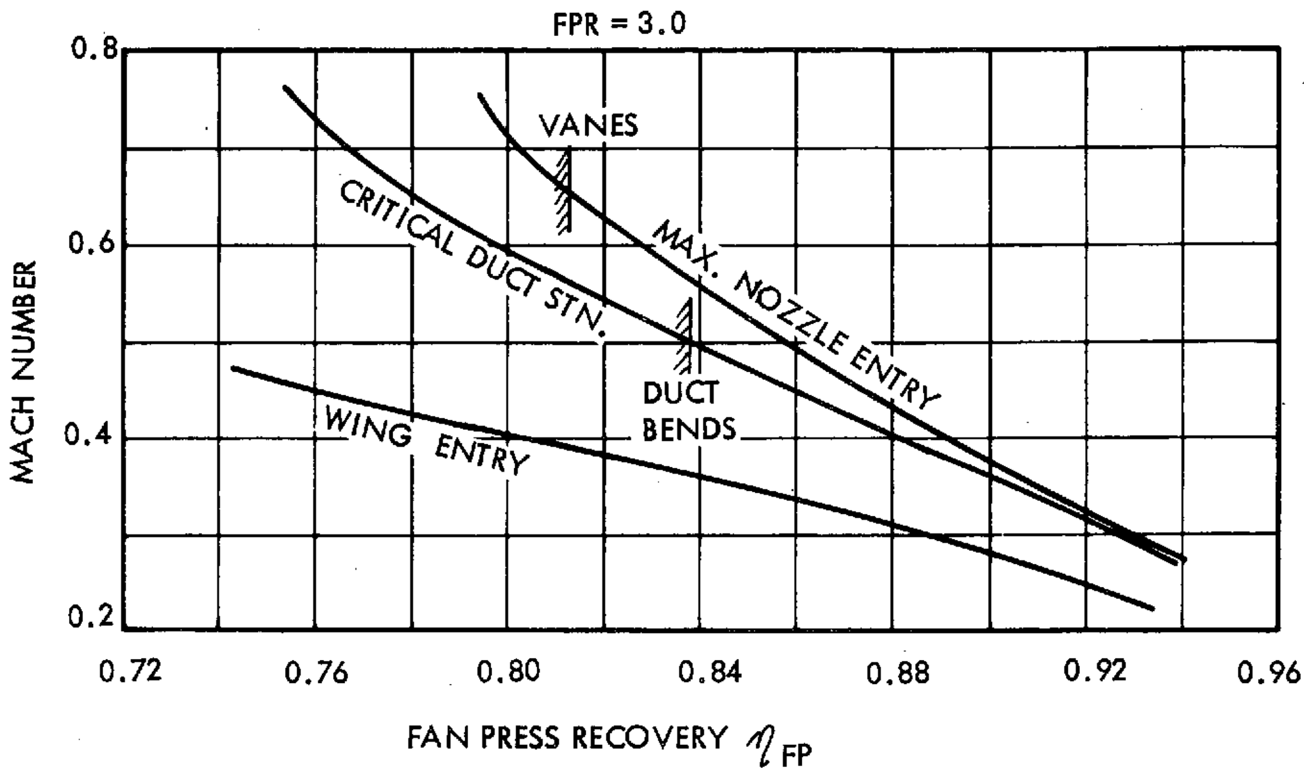


FIGURE 158: PROPULSIVE LIFT INSTALLATION LOSSES



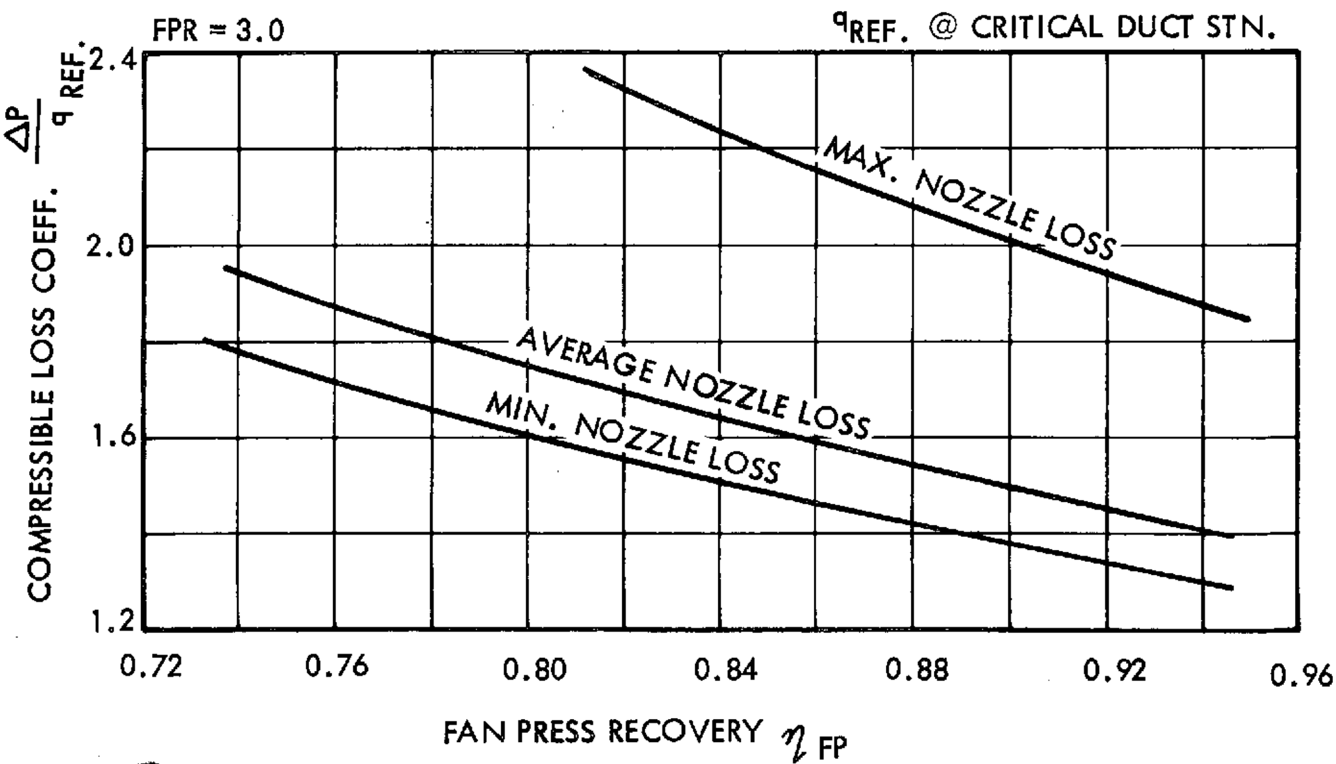


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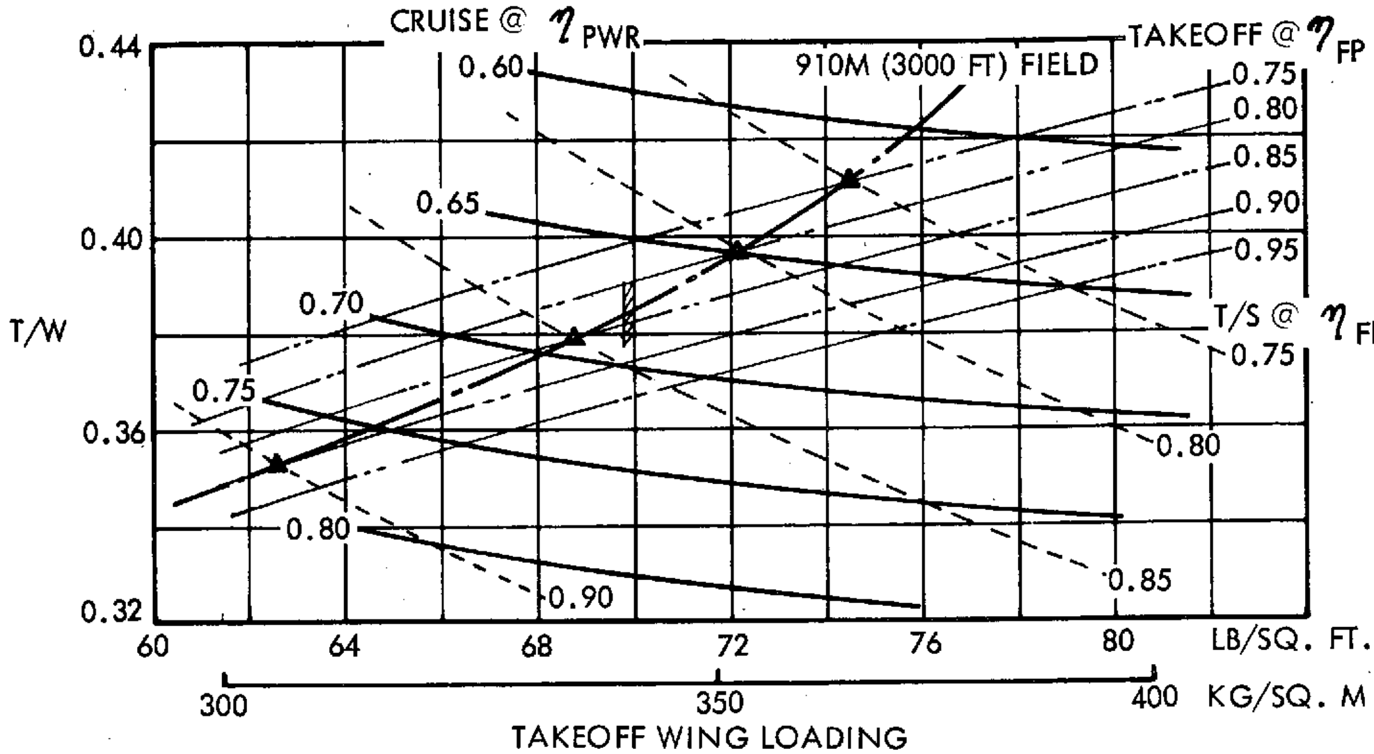
FIGURE 159: REFERENCE AW DUCT SYSTEM LOSSES

Applying different levels of design fan pressure recovery (0.75 - 0.95) simultaneously alters the takeoff T/W or T/W requirement by amending the augmentor thrust coefficient C_J and the attainable T/S limit because of the changes in duct mass flow. These effects upon the baseline two- and four-engine AW-2S vehicles are illustrated in the upper charts of Figures 160 and 161, respectively.

The intersection of the T/S and takeoff curves for similar values of η_{FP} defines a new curve indicating the best attainable takeoff performance of the AW-2S vehicles as shown. The corresponding effect upon the attainable DOC is shown in the lower charts of Figure 160 and 161. In either case, it is apparent that the minimum operating cost is theoretically attained at approximately 75% fan pressure recovery but in practice a target pressure recovery of approximately 85% is a limiting figure beyond which rapidly divergent pressure losses may be expected. These conclusions (with respect to the four-engine AW-2S) appear to be in general agreement with Boeing data shown in Figure 128 of NASA CR114534 which indicates a near minimum vehicle gross weight in the region of 14-15% fan pressure loss. It is noted that the four-engine vehicle is relatively insensitive to η_{FP} over a wide range of values but the twin engine vehicle is critically affected at pressure recoveries above 85%. Hence, the two-engine vehicle represents a much higher technical risk.

5.4.4 Wing, Nacelle, Ducting Integration

The sensitivity of DOC-1 (1972 fuel prices) to T/S limits for two and four engine AW vehicles is presented in Figure 162 in the context of the baseline mission speed and cruise altitude and the basic PD 287-51 engine (3.0 FPR). Subsequent studies of fuel-conservative AW vehicles have indicated that the mission fuel consumption and, by implication, DOC at elevated fuel prices is even more sensitive to T/S as shown in Figure 163. Hence, reliable estimates of the augmentor duct losses from which the T/S limits can be defined are needed for a realistic evaluation of the AW concept and attention has been directed to establishing the configuration geometry which will maximize that limit. The factors which influence this determination are not only sweep and aspect ratio (with which T/S is highly interactive) but also nacelle location relative to the wing, planform shape, FPR 3.0



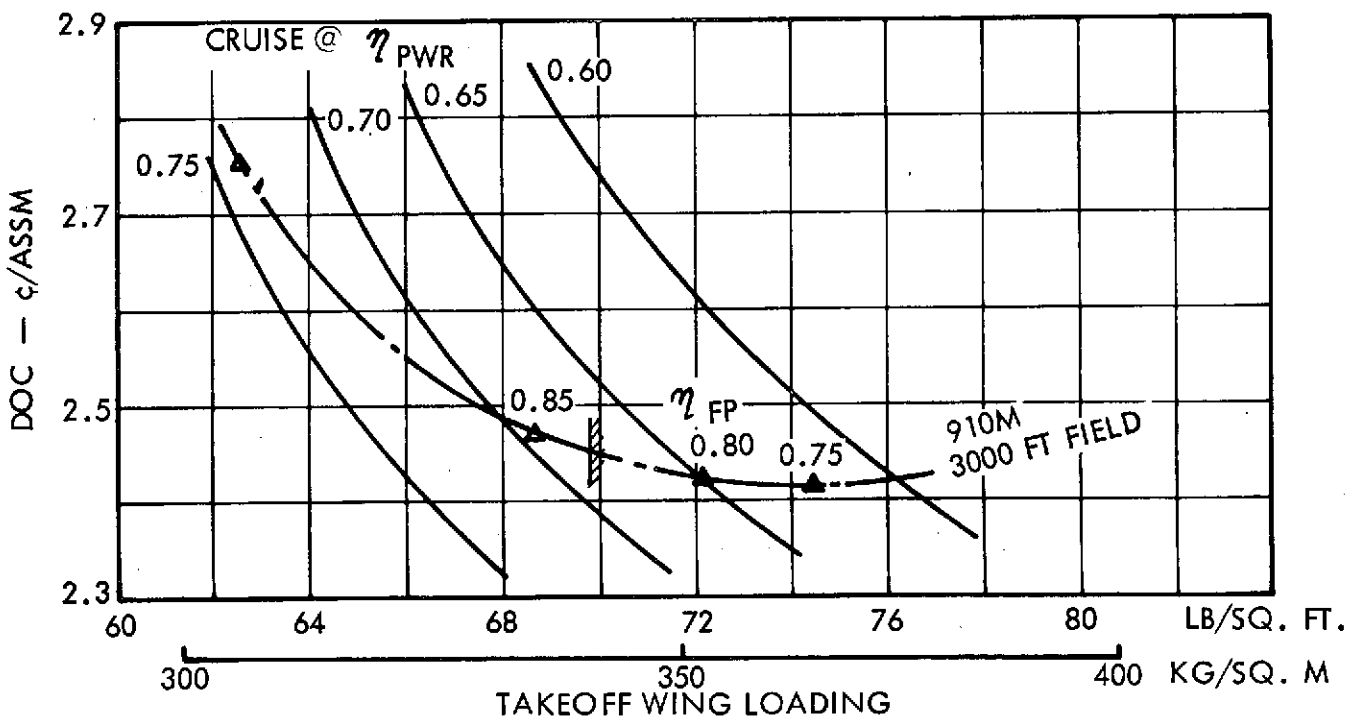
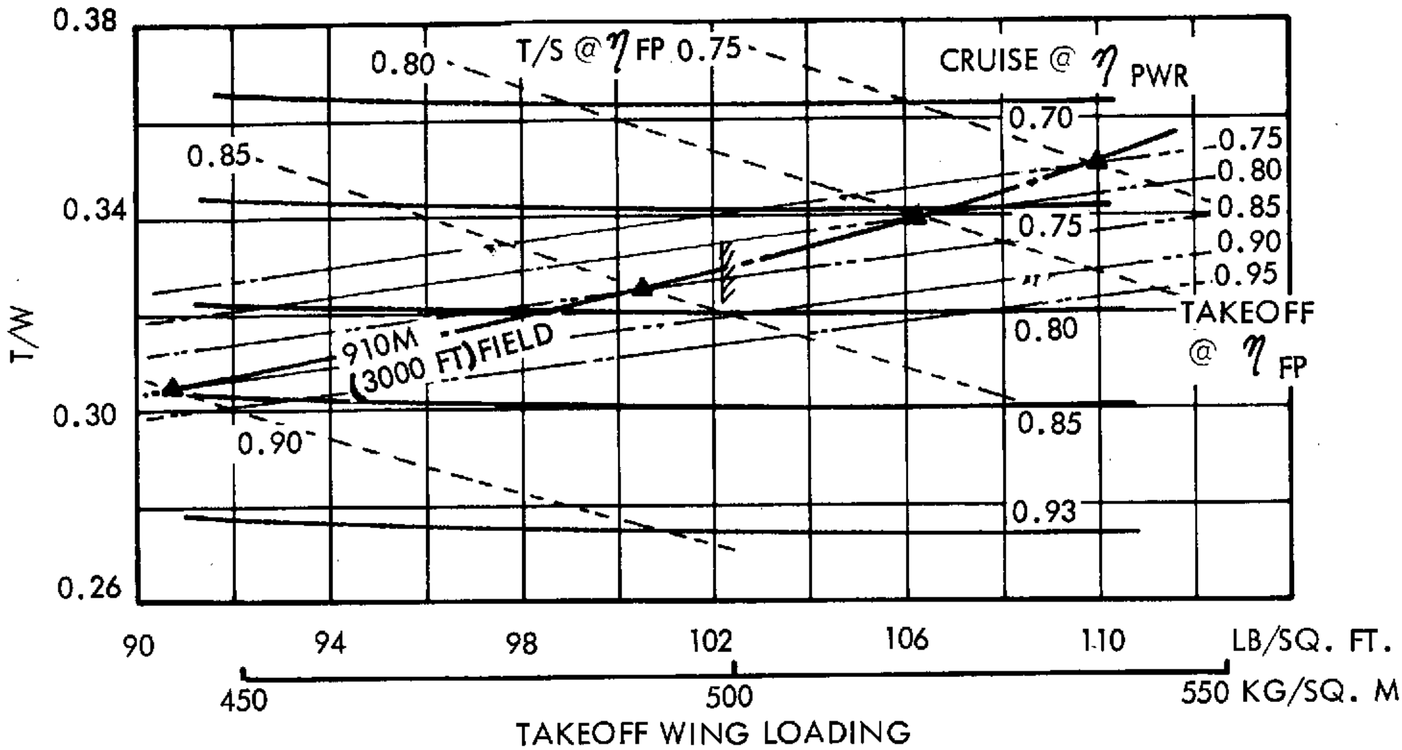


FIGURE 160: 2-ENGINE AUGMENTOR WING: OPTIMUM FAN PRESSURE RECOVERY

FPR 3.0



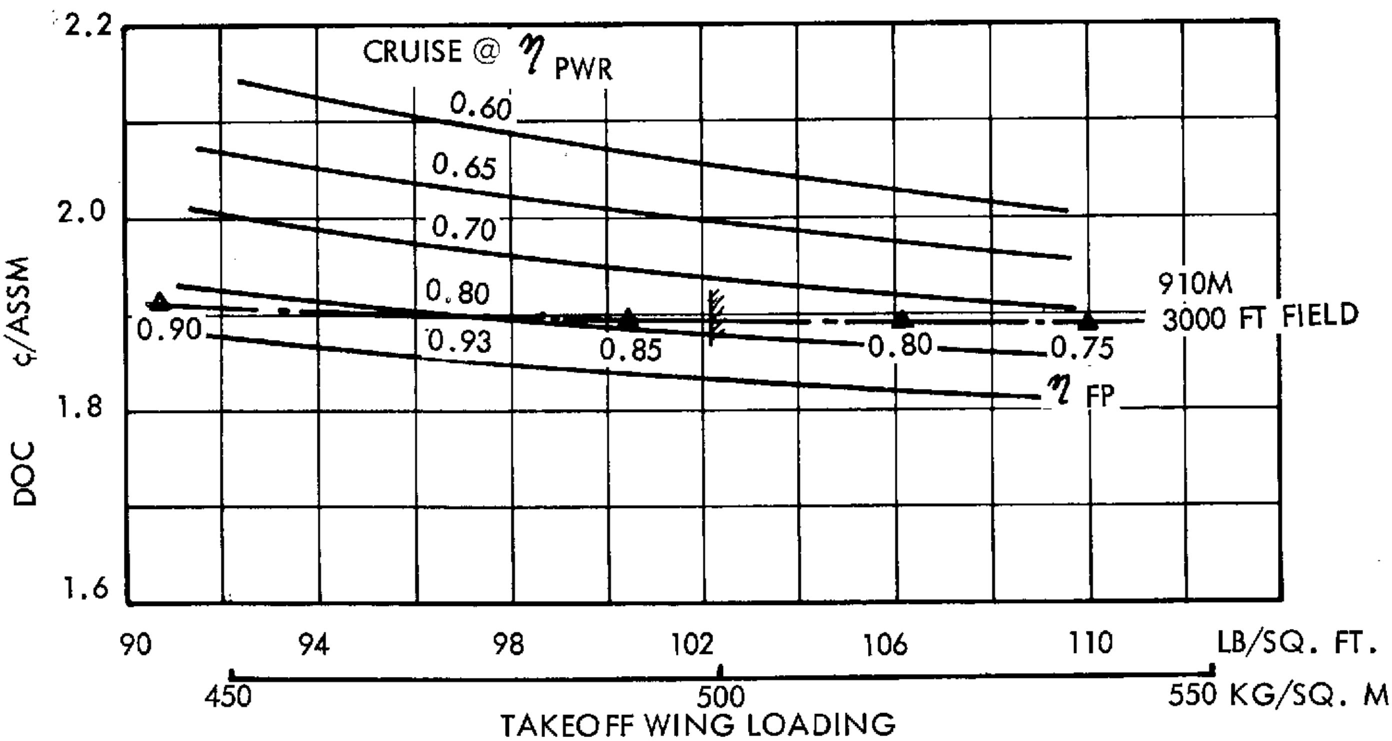


FIGURE 161: 4-ENGINE AUGMENTOR WING: OPTIMUM FAN PRESSURE RECOVERY

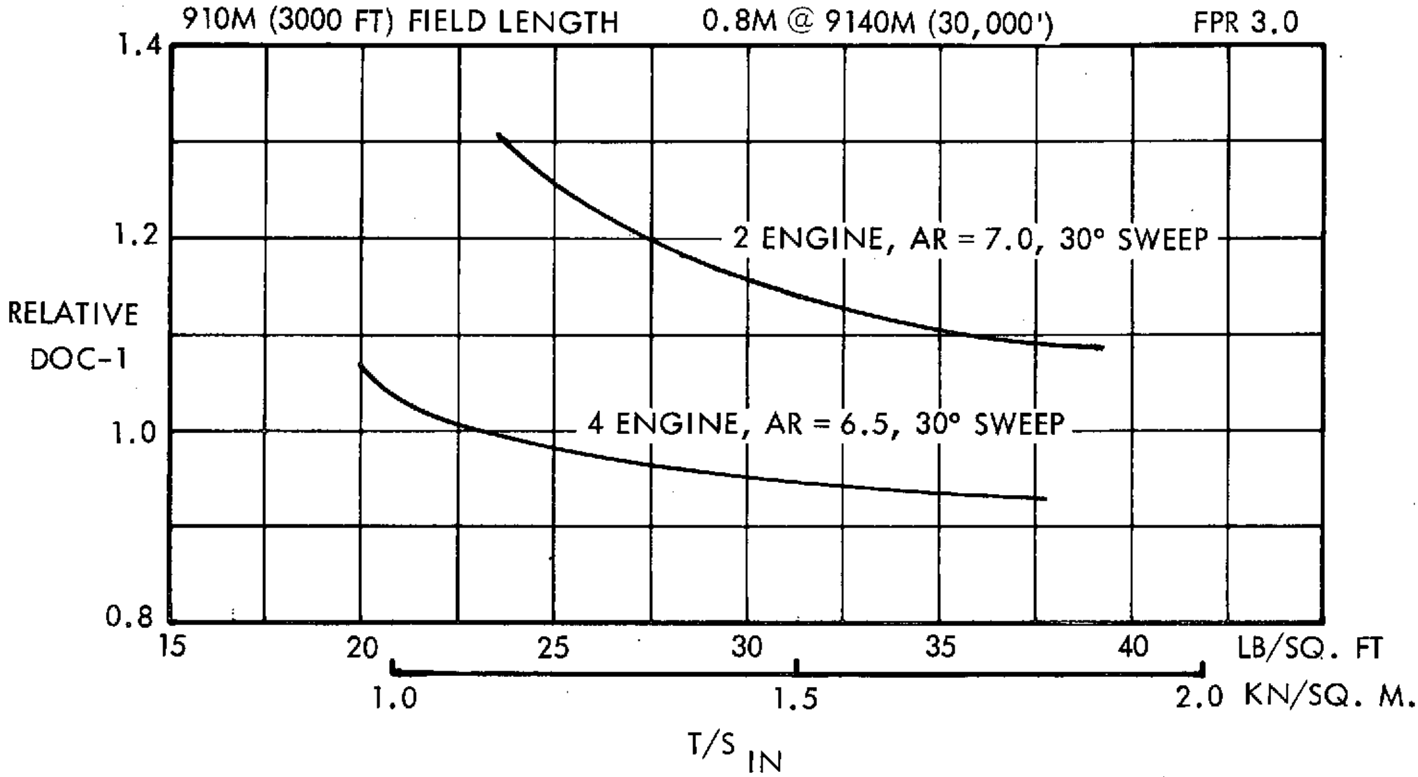


FIGURE 162: AW - DOC VS T/S

4 ENGINE AW @ FPR 3.2 AR = 7 20° SWEEP 0.75M
0.75M @ 10670M (35,000')

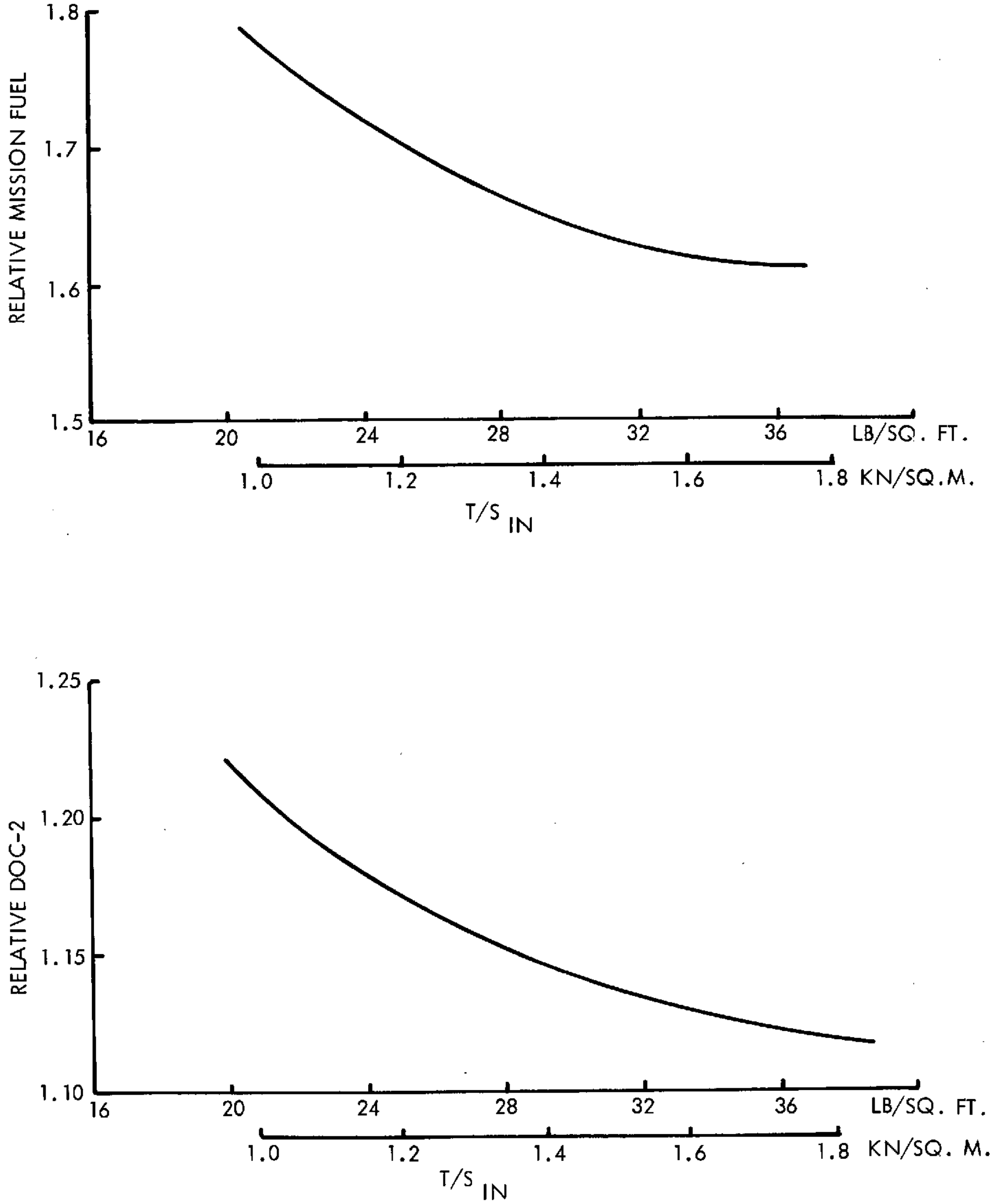


FIGURE 163: SENSITIVITY TO T/S LIMITS

taper ratio, airfoil thickness and its chordwise distribution as affected by the level of supercritical wing technology. (Moreover it can be shown that the relative size of the engine and wing involve an iterative loop in terms of wing and thrust loading for an exact solution.) The duct installation studies of NASA CR11462 (reference 2) have also indicated the sensitivity of losses in duct arrangements of the complexity shown in Figure 148 to superficially trivial factors such as the height:chord ratio of the duct stowage space and local "tailoring" or relative duct proportions at critical wing stations. One example of the latter is the local constriction of a transfer duct (supplying distant nozzles) in order to increase the size of an adjacent duct supplying local nozzles. The nozzle entry loss is a function of duct dynamic pressure, and thus proportional to the fourth power of duct diameter (or higher when compressibility allowance is made) and is a significant proportion of the overall system loss which makes this practice advantageous. For these reasons it has been found necessary to develop and analyze the alternate duct configurations in some detail for baseline vehicles in order to compare their pressure loss characteristics and T/S limitations and thus develop parametric T/S data for use in the configuration optimization and sizing of definitive vehicles. In the most general case of the four engine vehicles, this has involved the derivation of individual duct sizes and their most compact arrangement consistent with coupling, insulation and structural provisions at four key wing stations and up to four secondary stations per side in addition to sizing the nacelle and wing entry ducting.

Incompressible loss coefficients have been estimated recognizing individual component friction, turning and expansion losses and the methods of Reference 30 have been applied to estimate the resultant compressible flow losses. The engine size and nacelle ducting losses in each case have been matched with wing duct losses for an overall fan pressure loss of 15% at the augmentor nozzle and a common duct "inlet" Mach number of 0.35, i.e. it is assumed that the fan collector flow can be diffused to this Mach number at its exit for the quoted collector loss of 5% fan pressure (which is included in the overall 15% loss). The cruise loss of 6.1% fan pressure quoted in Section 5.2 includes allowance for the (closed) diverter valve which is assessed as an airframe component in the STOL mode. The diverter valve arrangements have been assumed to consist of ganged butterfly shut off valves in the wing entry and cruise nozzle ducts and a retracting cascade to turn the flow in order to avoid the rather high pressure losses in the cruise mode of the domed GE pattern valve quoted in the NASA-Boeing literature. No significant overall difference in the losses associated with the STOL mode has been postulated. The bifurcated wing duct entry component has also been assumed to be appropriately vaned to minimize losses arising from the bend and such diffusion as may be incurred in the interests of a low duct Mach number. The nozzle entry losses are predicated upon test data for the breakup nozzle wing duct offtake described by Boeing in NASA CR 114284.

Two Engine Vehicles - Consideration of the aggregate duct cross sectional area required (as represented by the arithmetic sum of individual duct mass flows) at each wing station for alternate spanwise nacelle locations (η) indicates that the maximum total area is independent of η . Thus the optimum spanwise nacelle location for independent ducts in a two engine arrangement is as far inboard as is practical. This has been taken to be determined by the ability to lower the engine change unit without the use of overhead hoists or other equipment nor normally available in terminal areas. Were the use of a plenum duct to be feasible, the optimum location would be further outboard in the region of 35% semispan (as may be deduced from the algebraic sum of the "individual" duct flows previously noted). Hence, the configuration options considered for two engine vehicles have chiefly concerned the effect of taper ratio and planform shape upon a dual independent duct system with the typical duct, nozzle and flap arrangement at the critical nacelle centerline station illustrated in Figure 164 . The following planforms were considered:

1. Conventional straight taper
2. Parallel center section from nacelle to root
3. Dual taper (or bat-wing) with the break station at the flap/aileron junction and at outer panel taper ratio of 0.67.

In each of the above, the spar locations were taken to be at 20% and 50% chord and as indicated in Figure 164 only a modest proportion of the airfoil cross section between 50% and 70% chord can be utilized effectively as flow area in any arrangement of two

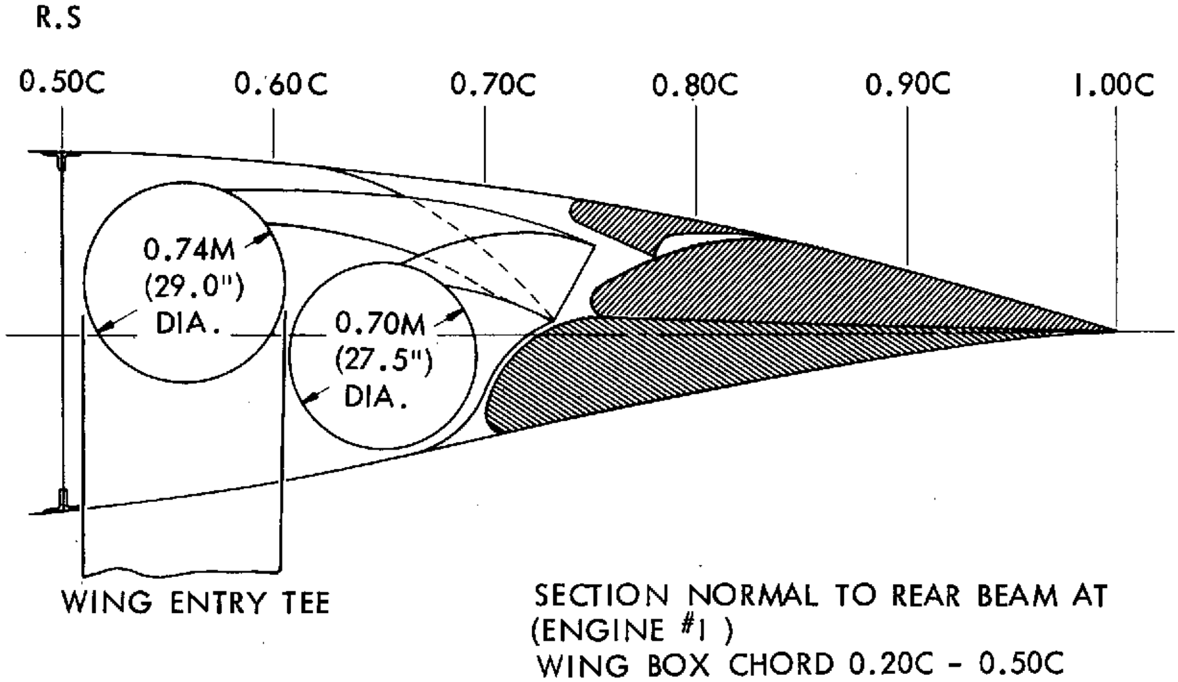


FIGURE 164: AW - DUCTING (2 ENGINE CONFIGURATION)

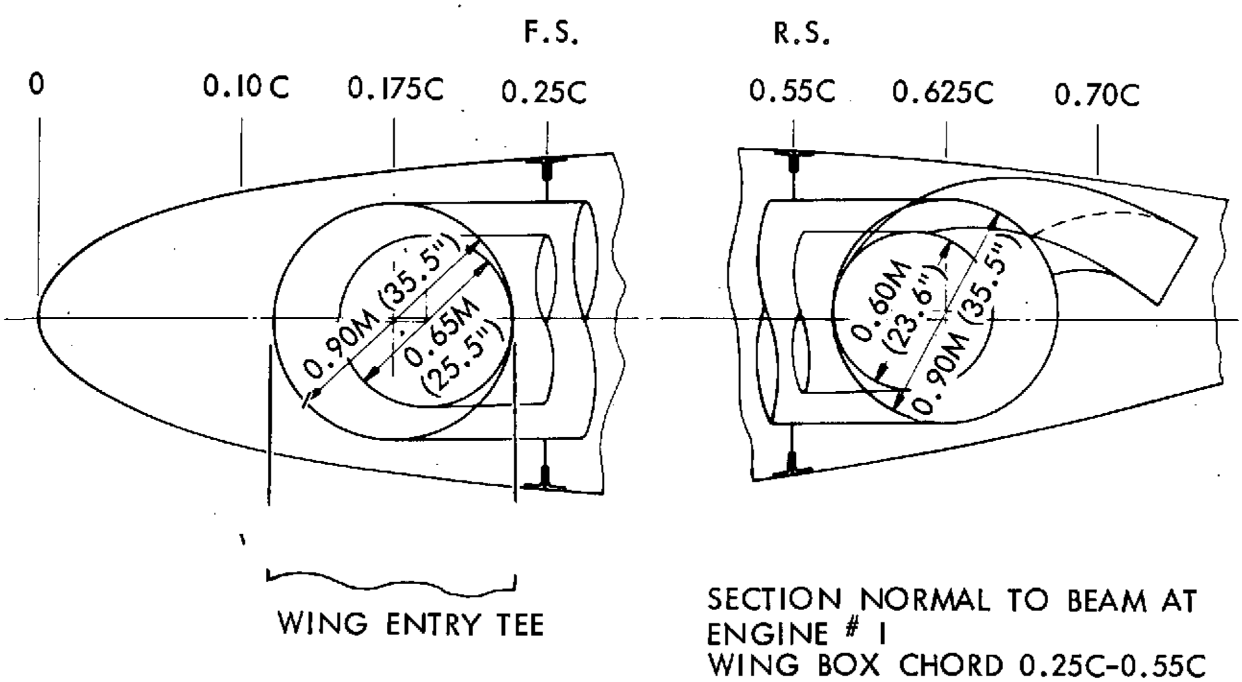


FIGURE 165: AW - ALTERNATE DUCTING (2 ENGINE CONFIGURATION)

near equi-sized ducts. Since a single circular duct in an almost square stowage area is more efficient in this regard, it was determined that a greater aggregate duct area would be possible with repositioning of the wing box and spar locations at 25% and 55% chord in a fore and aft arrangement of independent concentric ducts as illustrated in Figure 165 . The direction of the fan flow in the leading and trailing edge systems and the concentric ducts connecting them is indicated diagrammatically in Figure 166 and it will be recognized that there is a division of the chordwise duct flows entering each spanwise duct junction into (generall) unequal left and right hand components. Hence, if the inner and outer ducts are untapered in the region of the junction, as illustrated here, their relative sizes will be determined by the greater of these components in each duct. If the additional manufacturing complexity of tapering the inner duct over the junction is accepted, the proportional duct sizes will be determined by the local inner and outer duct flow components on either side of the junction. Accordingly, two concentric duct configurations have been evaluated on these alternate hypotheses with optimized spanwise nacelle locations in each case. The optimum location is further outboard than that for the orthodox dual duct system and its determination is a matter of some complexity.

The results of these duct analyses are presented in terms of the attainable T/S limit for each configuration option in Table XV. These data indicate that the attainable T/S limit of the initial 2 engine vehicle selection, with independent ducts for leading edge BLC, a taper ratio of 0.4, and the optimum fan pressure recovery, falls short of that postulated in its sizing by some 20%. However, the use of extreme taper (λ = 0.25) increases the T/S limit by over 20% and enables the original target to be approached with either plenum or independent leading edge BLC ducts. In view of the extreme inboard nacelle location the minor advantages to be gained by departing from a straight taper planform might have been anticipated. Despite the duct area advantages of the two concentric augmentor duct systems which were examined, the analysis shows that their additional friction losses, expansion losses and bend losses at junctions which cannot easily be vaned are prohibitive. Thus only marginally acceptable T/S limits are attainable in these systems when advantage is taken of the inherent asymmetries in the

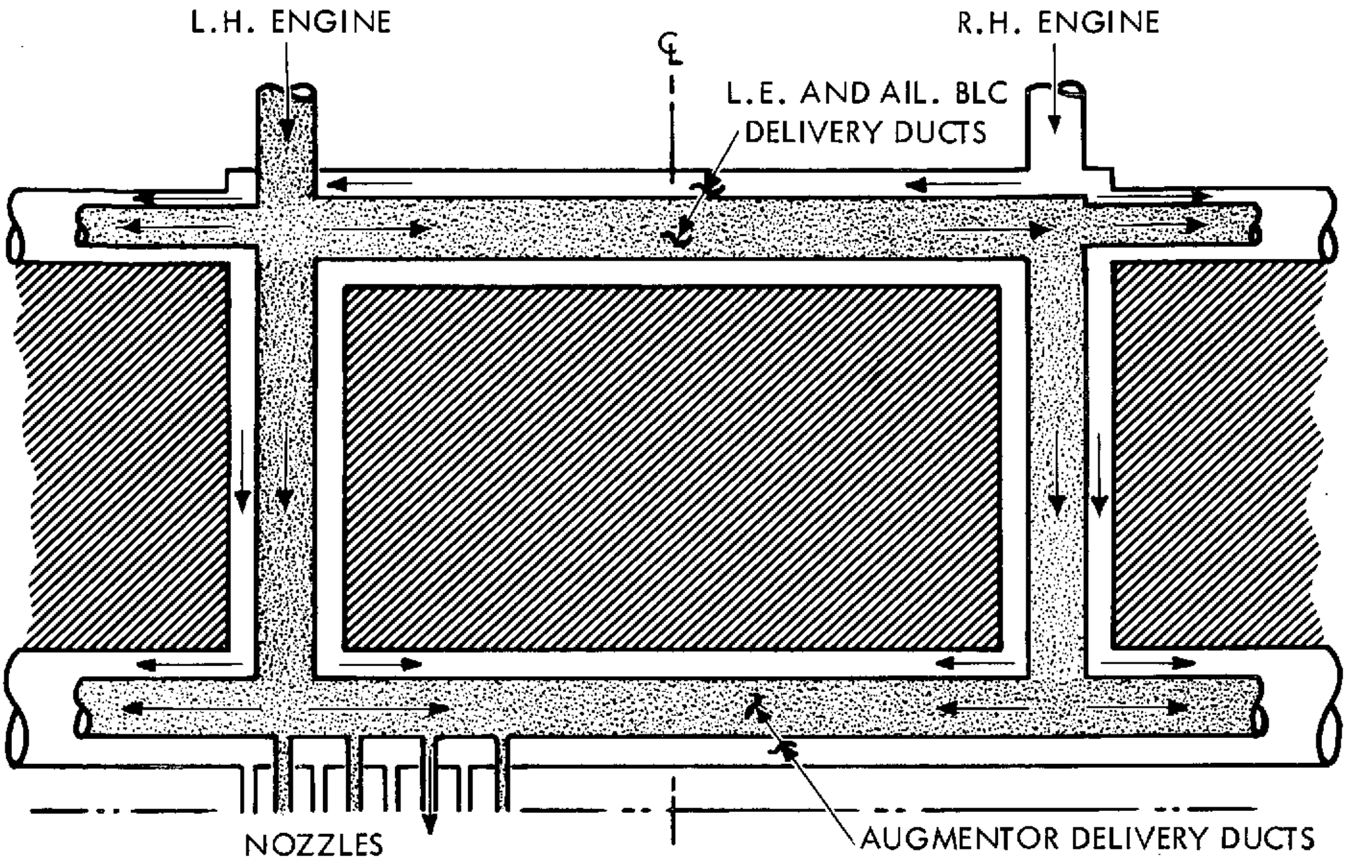


FIGURE 166: SCHEMATIC OF ALTERNATE 2-ENGINE DUCTING

VEHICLE CONFIGURATION	DUCT CONFIG.	η_{ENG}	PLANFORM	λ	T/S_{IN}*	NOTES
2 ENGINES AR = 7.0 Λ = 30° W/S = 69.0 LB/SQ.FT. = 337 KG/SQ.M. DDM 065 AIRFOIL	DUAL INDEPENDENT	0.140	ST. TAPER	0.40	19.0	PLENUM LE DUCT
					20.8	INDEP. LE DUCT
				0.25	22.9	PLENUM LE DUCT
					25.1	INDEP. LE DUCT
		0.140	PARALLEL C' SECTION	0.40	19.9	PLENUM LE DUCT
					21.8	INDEP. LE DUCT
				0.25	24.4	PLENUM LE DUCT
					26.7	INDEP. LE DUCT
	CONCENTRIC INDEPENDENT (1)	0.235	ST. TAPER	0.40	13.9	SYMMETRIC ENG. OUT
					16.8	ASYMMETRIC ENG. OUT
		0.245	PARRALLEL C' SECTION	0.40	15.5	SYMMETRIC ENG. OUT
					18.8	ASYMMETRIC ENG. OUT
	CONCENTRIC INDEPENDENT (2)	0.308	ST. TAPER	0.40	16.1	SYMMETRIC ENG. OUT
					20.3	ASYMMETRIC ENG. OUT
		0.313	PARALLEL C' SECTION	0.40	18.8	SYMMETRIC ENG. OUT
					23.8	ASYMMETRIC ENG. OUT
4 ENGINES AR = 6.5 Λ = 30° W/S = 998 LB/SQ. FT. = 487 KG/SQ. M. DDM 065 AIRFOIL	4 INDEPENDENT	OPT.	ST. TAPER	0.25	30.2	
				0.40	27.7	
	4 INDEPENDENT	OPT.	PARALLEL C' SECTION	0.25	34.7	
				0.40	31.6	
	4 INDEPENDENT	OPT.	BAT-WING	0.25	32.4	
				0.40	29.0	

* FOR 85% PRESSURE RECOVERY

TABLE XV: SUMMARY OF PRELIMINARY DUCT ANALYSES @ FPR 3.0

flow distribution to increase the leading edge flow outboard of each nacelle which results in an asymmetric lift distribution and rolling moment in single engine operation.

As a consequence of these studies, the preferred 2 engine configuration geometry was identified as a straight, highly tapered planform with an overwing nacelle at the wing root and a high wing location. The conflict between wing mounted landing gear stowage and trailing edge AW duct space precludes the adoption of the equivalent low-wing arrangement with an underwing nacelle. The T/S penalty for a more orthodox underwing nacelle location with one nacelle diameter fuselage clearance and a high wing arrangement was estimated to be approximately 15 % and therefore incompatible with an efficient overall vehicle. With this outboard nacelle location the parallel-chord-centersection planform would be advantageous for a twin engine vehicle.

Four Engine Vehicles - A corresponding set of configuration studies has been made of four engine vehicle duct arrangements with the typical duct, nozzle and flap arrangement at the critical outboard nacelle station which is illustrated in Figure 167 . Only three of the four independent ducts cross this station and the proportion of the airfoil section between 50% and 70% chord which can be utilized for the ducts is again modest as the figure shows. The aggregate duct area required at the outboard nacelle is identical with that required for the four ducts crossing the inner nacelle station if a uniform duct velocity is to be achieved, as can be deduced from the arithmetic sum of individual duct flows at each spanwise station. However, the shorter wing chord, and by implication the smaller available cross section, at the outer nacelle in a straight tapered wing creates the mismatch, (between available and desired duct sizes) which is illustrated in Figure 168 Hence, high local duct Mach numbers are associated with the outboard nacelle in a straight tapered wing which may become excessive (as discussed in Section 5.4.3) before the average nozzle pressure loss does, since the lower losses associated with the lower duct velocities for the inner engine ducts partially redress the balance in the latter respect. Accordingly, the use of a parallel center section planform in which a closer match between the individual ducts themselves and the space available (as indicated in Figure 168) appears attractive for the four engine AW and has been represented in the candidate planforms. Optimum nacelle locations (and thus the optimum planform

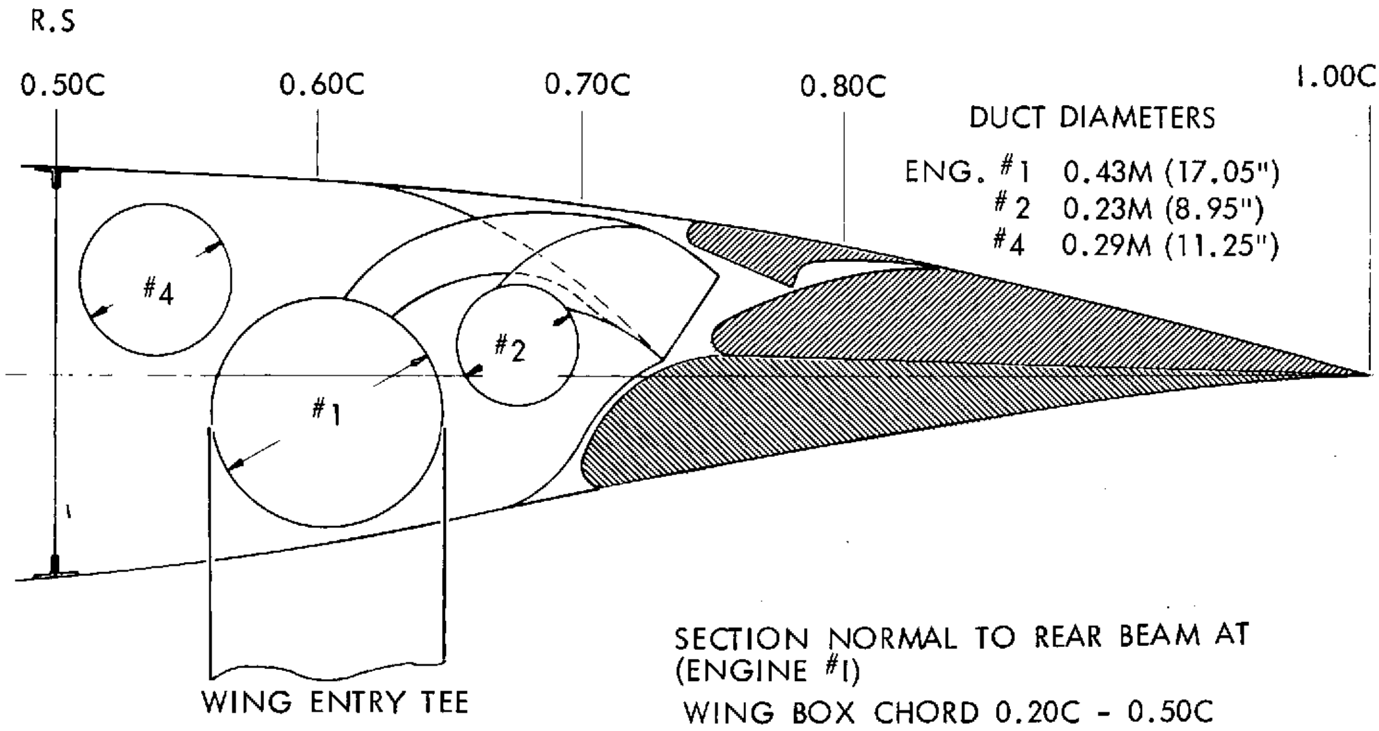


FIGURE 167: AW - DUCTING (4 ENGINE CONFIGURATION)

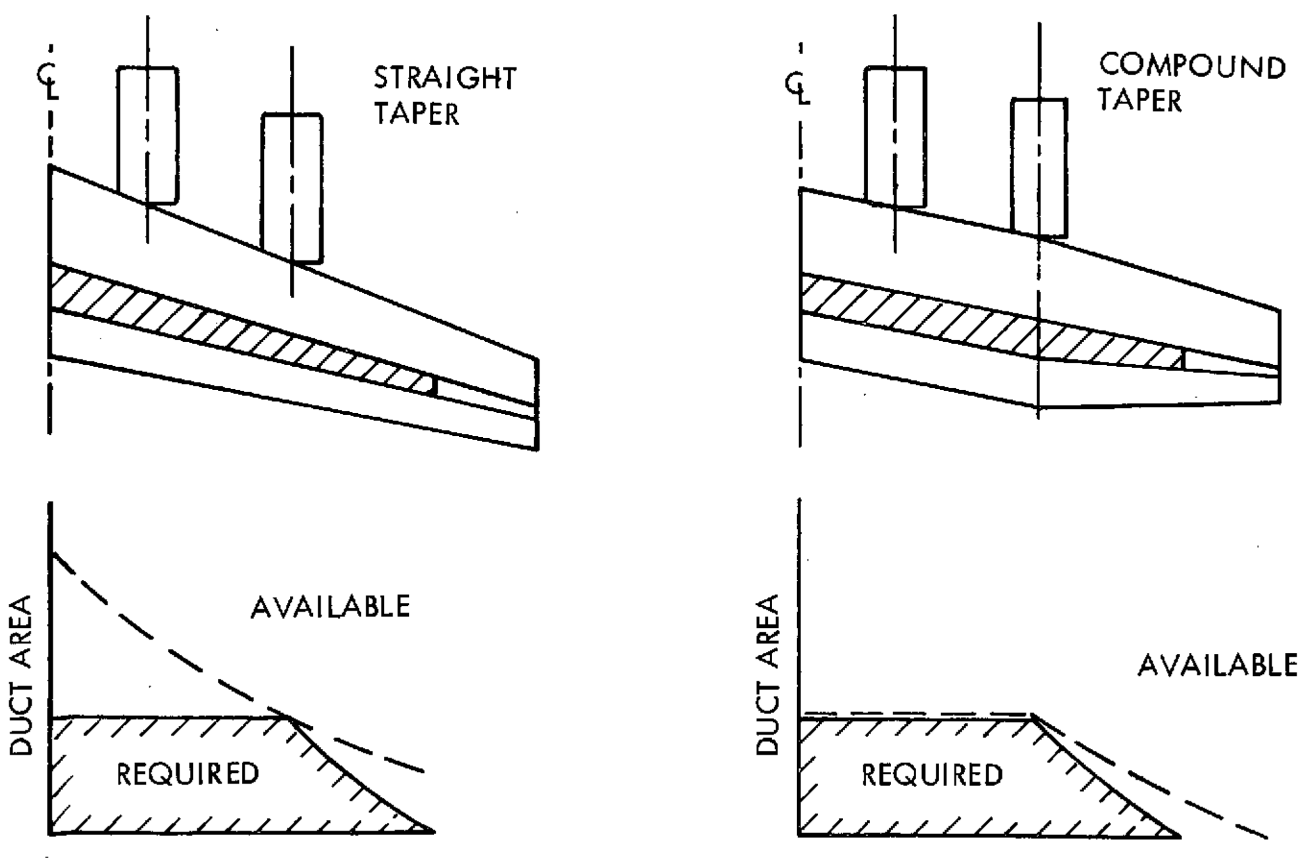


FIGURE 168: AW - MATCHING OF PLANFORM AND DUCT AREA

break station) have been derived for each planform as a function of aspect ratio and wing loading for 910m. (3000 ft.) field length vehicles and are presented in the appendices to this report. These data indicate that whereas an overwing nacelle location is implied for the lower aspect ratios, orthodox underwing installations incur no T/S penalty at the higher aspect ratios to be expected in fuel conservative vehicles.

The results of these comparative analyses have already been included in Table XV for ready comparisons to be drawn with the two engine configurations. These data again indicate that the T/S limit upon which the initial 4 engine vehicle selection was predicated is not attainable with a straight tapered wing but is achievable with the approximately 14% improvement attributable to compound taper. Moreover, this improvement can be stretched to 20% or more when associated with a high overall taper (λ = 0.25). Hence, the preferred 4 engine configuration geometry has been identified as having a highly tapered planform and a parallel centersection with the break station defined by the outboard nacelle location. The latter may be associated with a minimum nacelle spacing dictated by interference drag considerations and an underwing nacelle arrangement but in an idealized configuration, an optimum nacelle location which may imply overwing nacelles is defined.

Cruise Blowing - A typical distribution of the fan pressure losses among the augmentor system components, as derived from the foregoing duct analyses, is presented in Figure 169. Approximately 10% is attributable to the diverter valve which can be eliminated in the 'cruise blowing' or 'valveless' concept proposed by Boeing (in NASA CR 114570) whereby multiple overwing nozzles are substituted for the discrete cruise nozzle and utilized in both STOL and cruise modes. A reduction of 3.5% in the gross weight and a similar increase in the wing loading of a representative vehicle are reflected in the Boeing data but no DOC comparisons are drawn.

A tentative evaluation of such a system has been made in the context of the baseline mission vehicles reported here and was predicated upon increasing the wing thickness of a four engine vehicle by 10% (as appears to be indicated by the Boeing data). If this

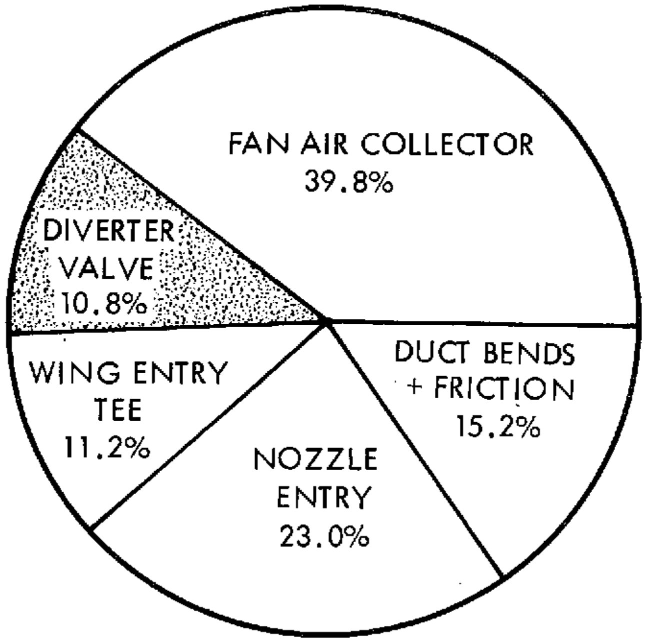


FIGURE 169: AW - DISTRIBUTION OF FAN PRESSURE LOSSES

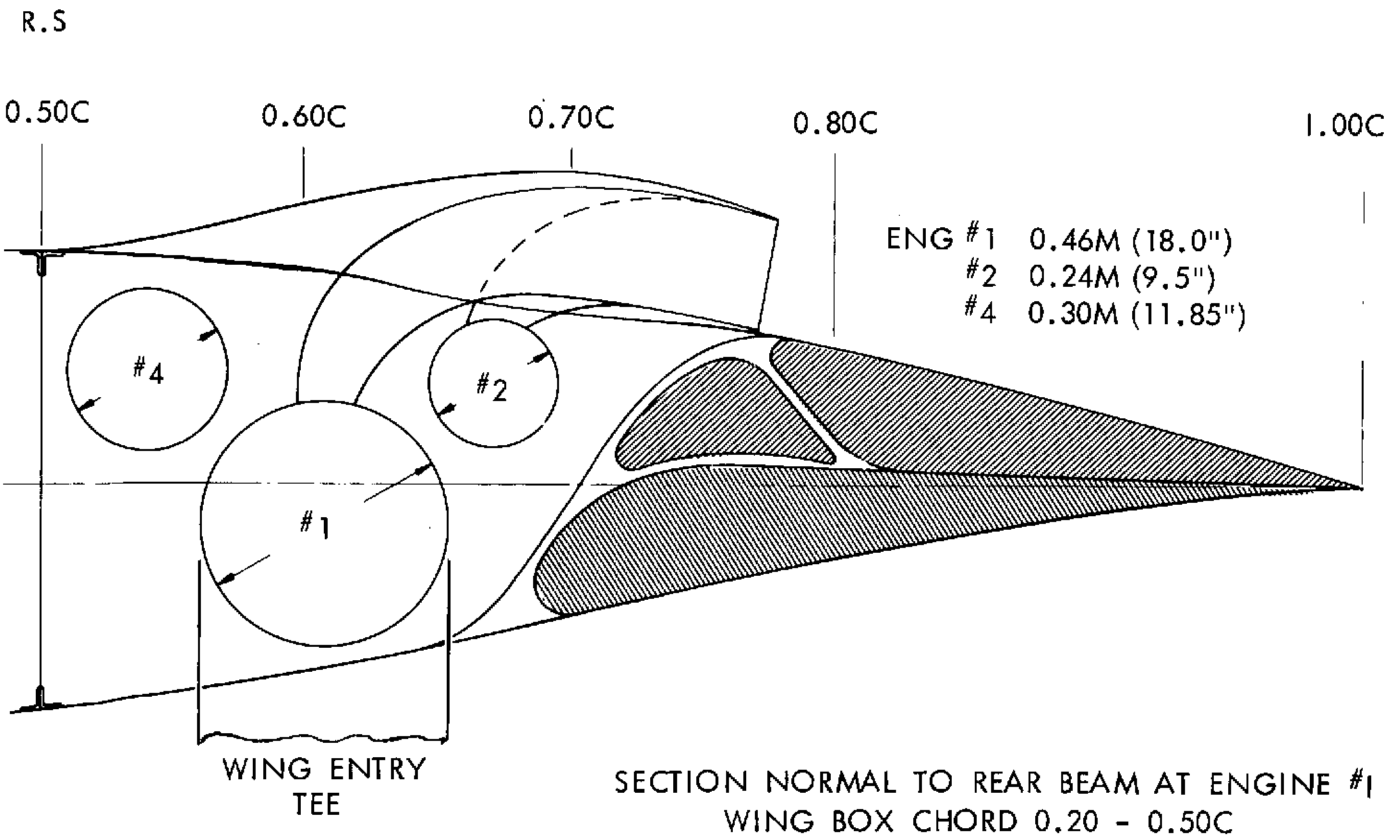


FIGURE 170: AW - CRUISE BLOWING DUCTING (4 ENGINE)

is ascribed to the "Whitcomb body" effect of the multiple trailing edge nozzles, the proportional increase in thickness-chord ratio becomes a function of both aspect ratio and T/S in which respect the Boeing and Lockheed configurations differ slightly. Accordingly, an upper bound to this increment has also been postulated in direct ratio to the trailing edge flux per unit span for comparative purposes. Augmentor ducts have been sized for both cases and the system losses estimated to derive comparative T/S limits for orthodox and cruise blowing vehicles. Figure 170 presents cruise blowing duct sizes and nozzle arrangements, on the first premise, that are directly comparable with the orthodox configuration which has been shown in Figure 167. Figure 171 compares the orthodox (full lines) and cruising blowing (broken line) vehicles in terms of their cruise and takeoff requirements for alternate cruise power settings (η_{PWR}) and indicates their respective T/S limits. These data are referred to the installed T/W for takeoff with 85% fan pressure recovery. Hence, the T/W required for 910m. (3000 ft.) field length is unaffected by the differences between the augmentor duct systems (which appears as a substantially increased T/S limit attributable to the cruise blowing system). However, the increased cruise losses of the cruise blowing system relative to take-off installation losses (which may be regarded as effectively increasing the thrust-altitude lapse rate) are reflected in an increase in the equivalent takeoff T/W for cruise at any specific power setting. Thus, the matching of the respective T/S limits with takeoff requirements indicates that the cruise blowing vehicle has an 8% higher wing loading and 3% higher installed thrust loading than the orthodox vehicle assuming 10% increase in wing thickness/chord ratio (t/c). At the postulated upper bound to the potential t/c increment (17%) which is associated with a radically increased T/S limit the increase in wing loading is of the order of 20%. However, the relatively larger fuel fraction and engine weight constrain the potential reduction in DOC to around 1% on the most optimistic assumptions and actually increase DOC by 0.3% on the more pessimistic assumptions. Hence, little or no practical benefit is envisaged for the cruise blowing system in this context. Were the initial vehicle to be more heavily T/S limited to rather smaller wing loadings, the cruise blowing system might appear to greater advantage (although it should be noted that no drag penalty such as has been discussed in Section 5.3.2 has been attributed to the system in this appraisal). It has been concluded that the maximizing of the T/S limits by suitable selection of the configuration geometry is a more effective measure for optimizing the AW concept in this mission context.

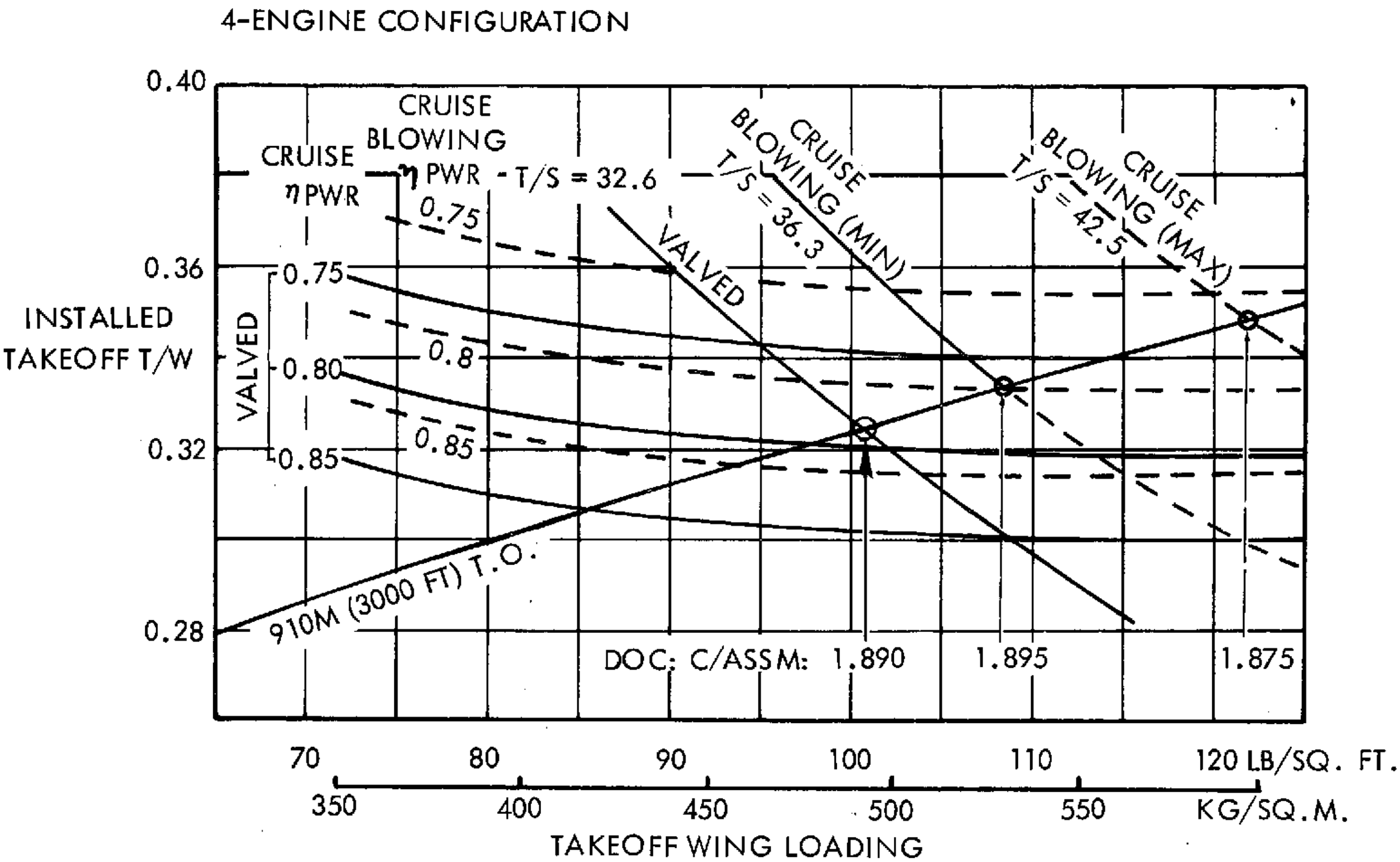
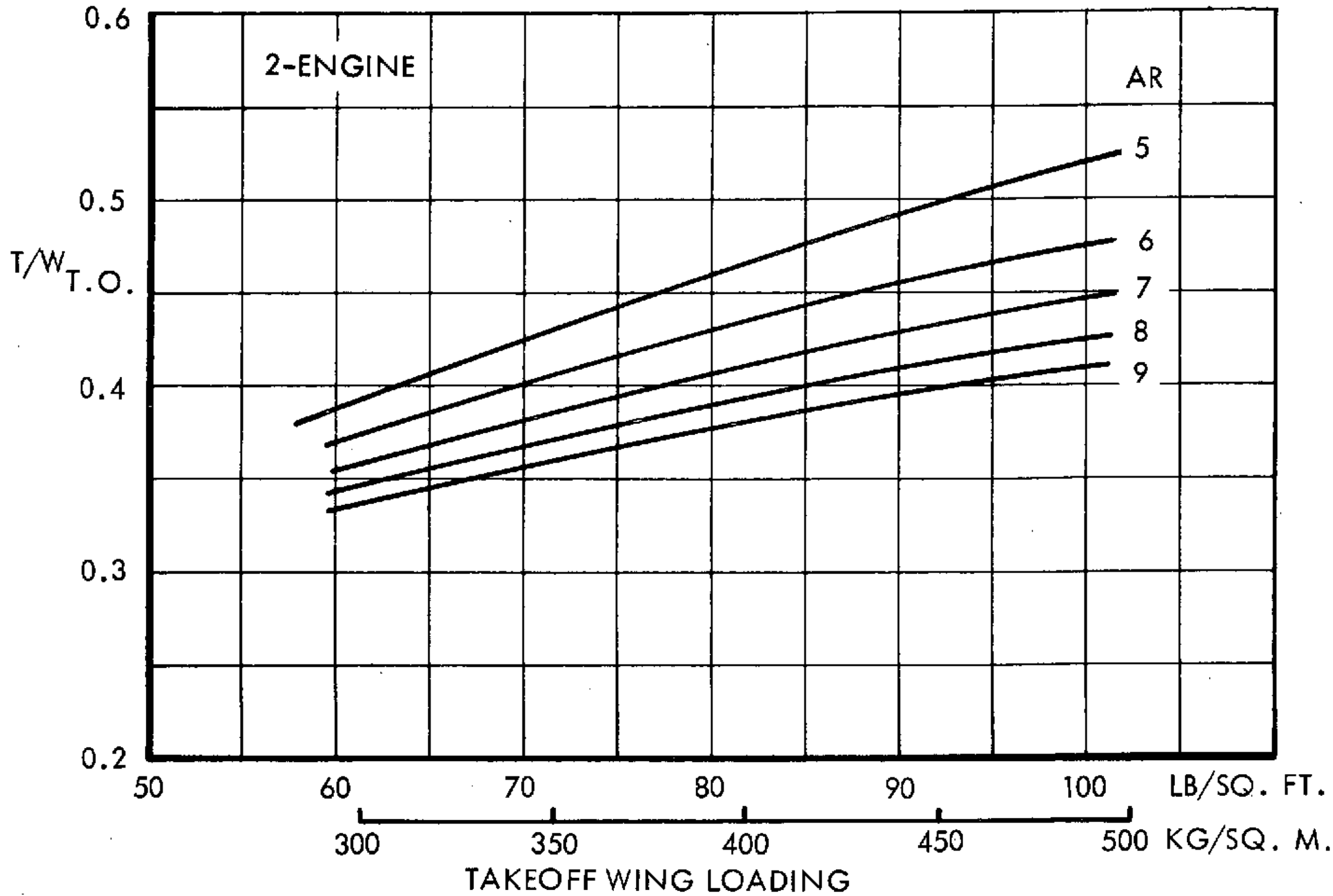


FIGURE 171: AW - COMPARISON OF VALVED AND CRUISE BLOWING SYSTEMS

5.4.5 Optimum Aspect Ratio and Sweep

The optimum aspect ratio and sweep for baseline mission two and four engine vehicles have been determined from a matrix of mission sized vehicles with aspect ratio varying between 5 and 9 and sweep angles of 15° to 40°. Parametric T/S limits have been applied in this process on the basis of the duct analyses described in Section 5.4.4 and the thrust and wing loadings required for 910m. (3000 ft.) takeoff have been derived as a function of aspect ratio as presented in Figure 172. Field performance has been taken to be invariant with sweep angle on the basis of the arguments presented in Section 5.3 and it will subsequently be noted that the preferred configurations have small sweep angles which fully justify this simplified approach.

As has been implied in Section 5.4.4, an iterative process is involved in correctly matching T/S, T/W and W/S when sizing the AW vehicles for a range of aspect ratio and sweeps. The results of a first iteration based upon the level of airfoil technology designated DDM 065 and a taper ratio of 0.4 for the two- and four-engine vehicles is presented in Figure 173 . This figure shows the two-engine vehicle to be highly sensitive to the choice of aspect ratio and sweep because it is severely constrained by its T/S limit and field performance to uneconomically low wing loadings. In constrast, the effect of varying aspect ratio and sweep on the four-engine vehicle is almost trival for wide departures from the optimum. In each case, the optimum aspect ratio has been shown to be 5.5 and the preferred sweep 20° by this first iteration in which the lower bound to sweep has been defined by preliminary aeroelastic considerations. A more precise aspect ratio optimization study was subsequently accomplished at the selected sweep angle of 20° and with slightly modified parametric wing weight equations to reflect the aspect ratio effects indicated by more detailed analyses with greater accuracy. Furthermore, the assumed level of supercritical airfoil technology was raised (to DDM 080 which designates a drag rise Mach number increment of 0.08 relative to a particular reference airfoil) for consistency with the other lift concepts. Whereas both T/S and some wing weight advantages can be attributed to this type of airfoil for OTW-IBF applications because of the deeper wing box and larger chordwise ducts it permits, the net T/S advantage for AW applications is trival since the shallower depth of the aft section balances the increased overall thickness chord ratio.



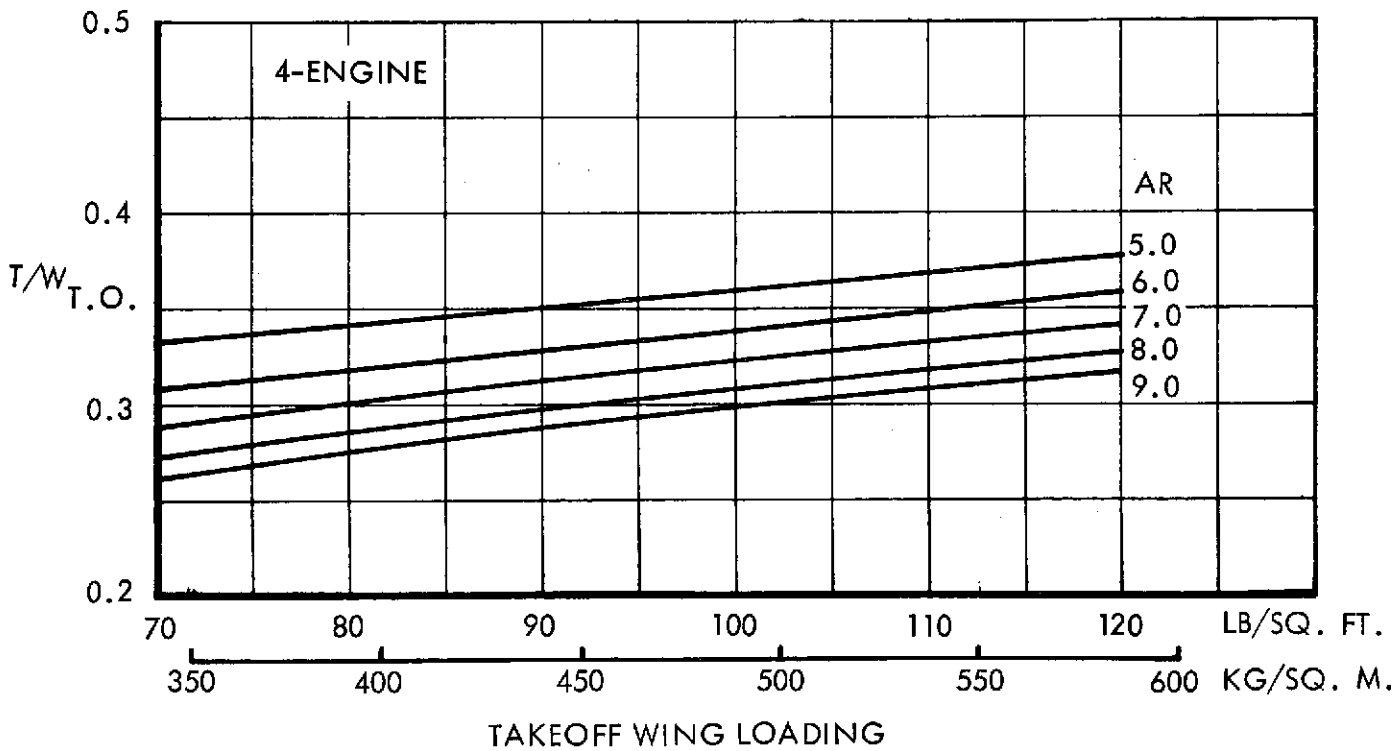


FIGURE 172: THRUST/WEIGHT VS TAKEOFF WING LOADING
AUGMENTOR WING

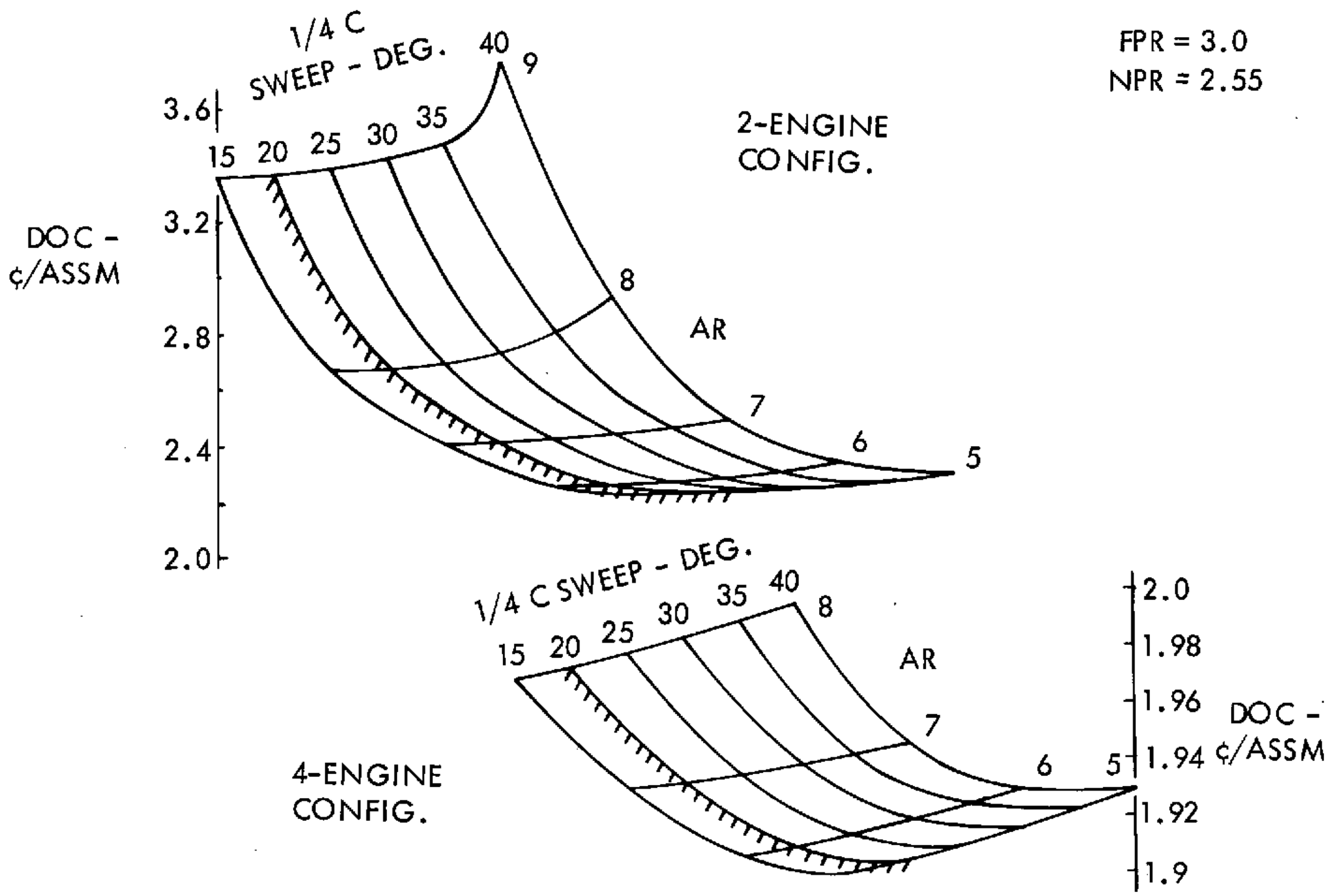
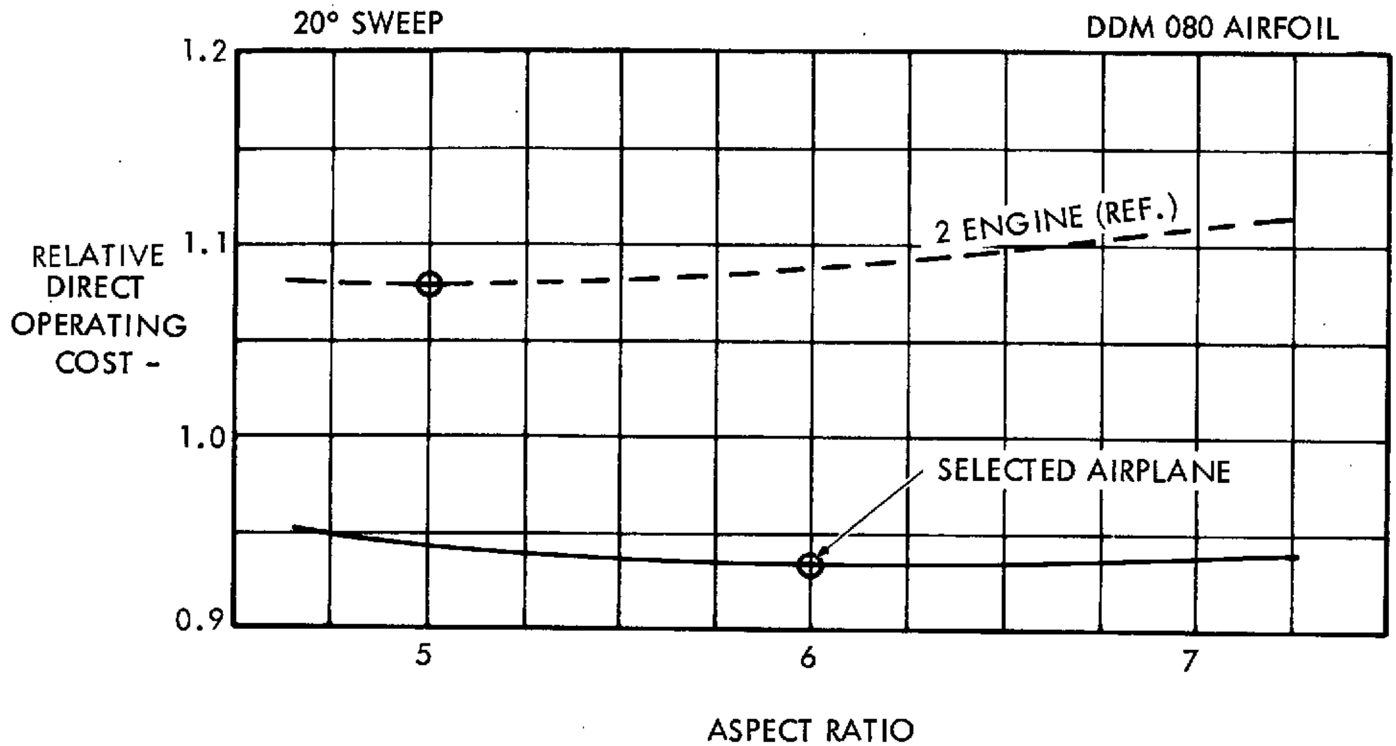


FIGURE 173: AW - DOC VS ASPECT RATIO AND SWEEP (INITIAL)

Figure 174 presents the effect of aspect ratio selection upon alternate operating cost and mission fuel selection criteria for two and four engine vehicles. It should be noted that DOC is quoted in the context of 1972 fuel costs and the preferred aspect planes have been selected accordingly for the baseline mission. The preferred aspect ratio of 5.0 for the two engine airplane is rather lower than the AR 6.0 associated with four engines in order to alleviate an intrinsically greater T/S sensitivity. Both vehicles exhibit lower optimum aspect ratios than the other lift concepts because of their more pronounced T/S constraints. Figure 174 also indicates that higher aspect ratios are required to minimize mission fuel and it can be inferred that optimum configuration selections based upon DOC at elevated fuel prices would shift in the same direction. Whereas the scope for fuel saving in the two engine configuration is limited since increasing wing weight at the relatively low wing loading and the associated increase in gross weight overcome the fuel benefits of higher aspect ratio in the region of AR = 6.0. Regardless of the selection criteria used, the clear superiority of the four engine AW configuration (which was first noted in the critical vehicle selections) over the alternate two engine arrangement has been shown to be maintained after configuration optimization in each case.

5.4.6 Selected Baseline Mission Vehicles

Configuration sizing data for the selected two engine vehicle at the preferred sweep and aspect ratio are presented in Figures 175 and 176. The general arrangement of the selected vehicle is presented in Figure 177. Similarly, Figures 178 through 180 present sizing data and a 3-view of the selected four engine vehicle. Their leading characteristics are presented in Table XVI. The mission fuel requirements are indicative of the fuel penalties incurred by the restriction of this concept to high FPR engines with relatively high cruise sfc and low thrust-altitude lapse rates, which lead to the fairly low part power cruise techniques indicated in Figures 175 and 176.



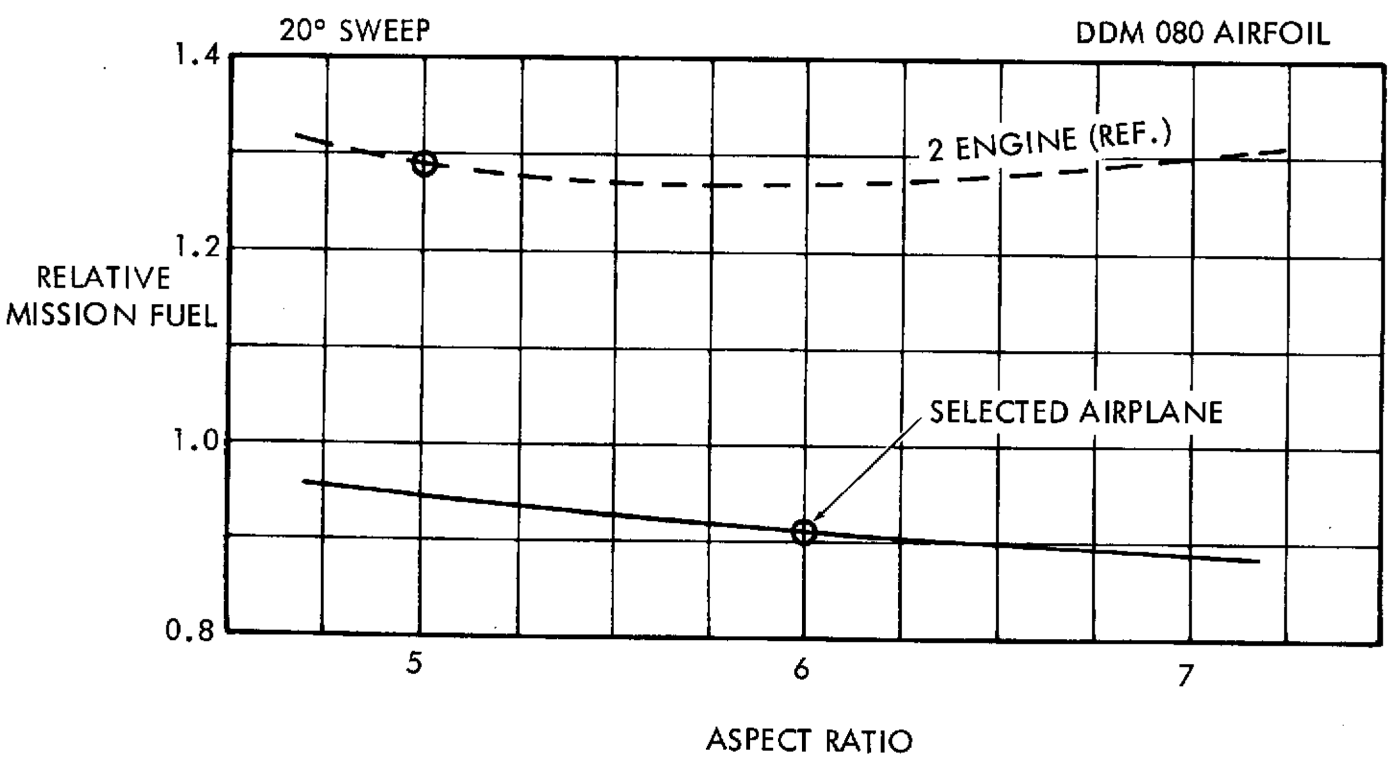


FIGURE 174: RELATIVE DOC & MISSION FUEL VS ASPECT RATIO

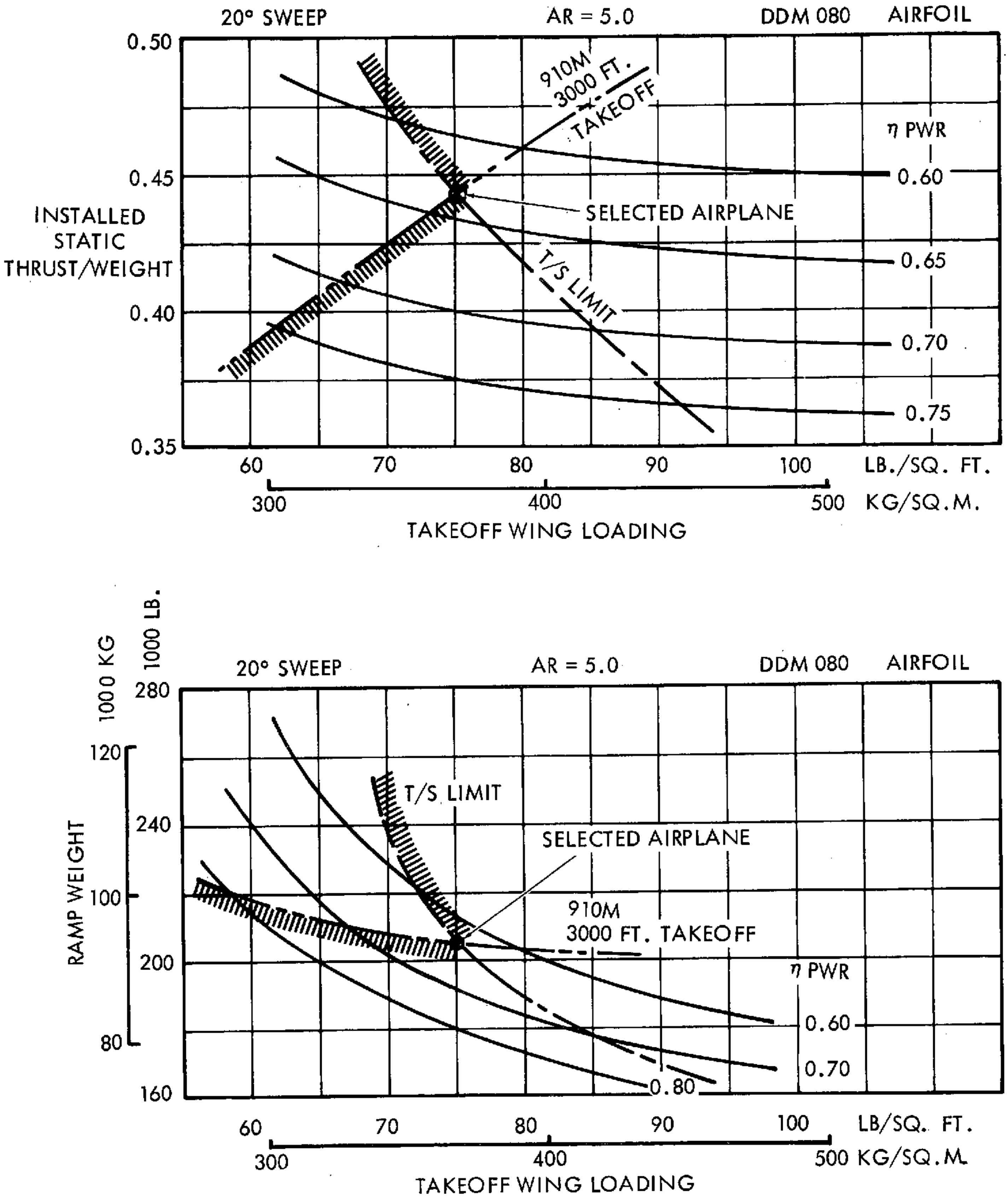


FIGURE 175: AW - T/W AND RAMP WEIGHT VS W/S (2 ENGINES)

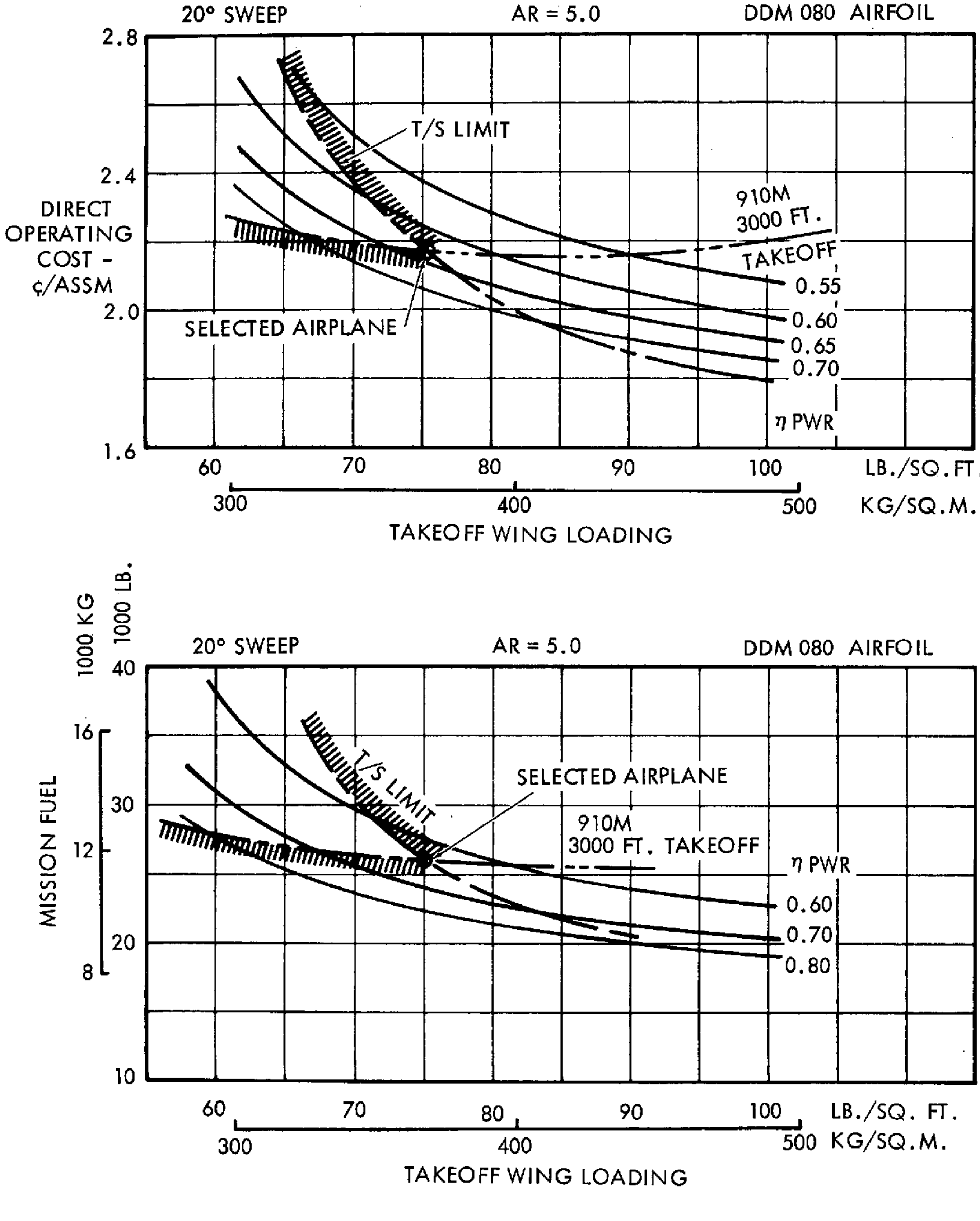


FIGURE 176: AW - DOC AND MISSION FUEL VS W/S (2 ENGINES)

148 PAX
0.8 M
910M (3000 FT.) FIELD LENGTH

SPAN = 114' (34.75M)
LENGTH = 144.3' (43.98M)
HEIGHT 44' (13.41M)

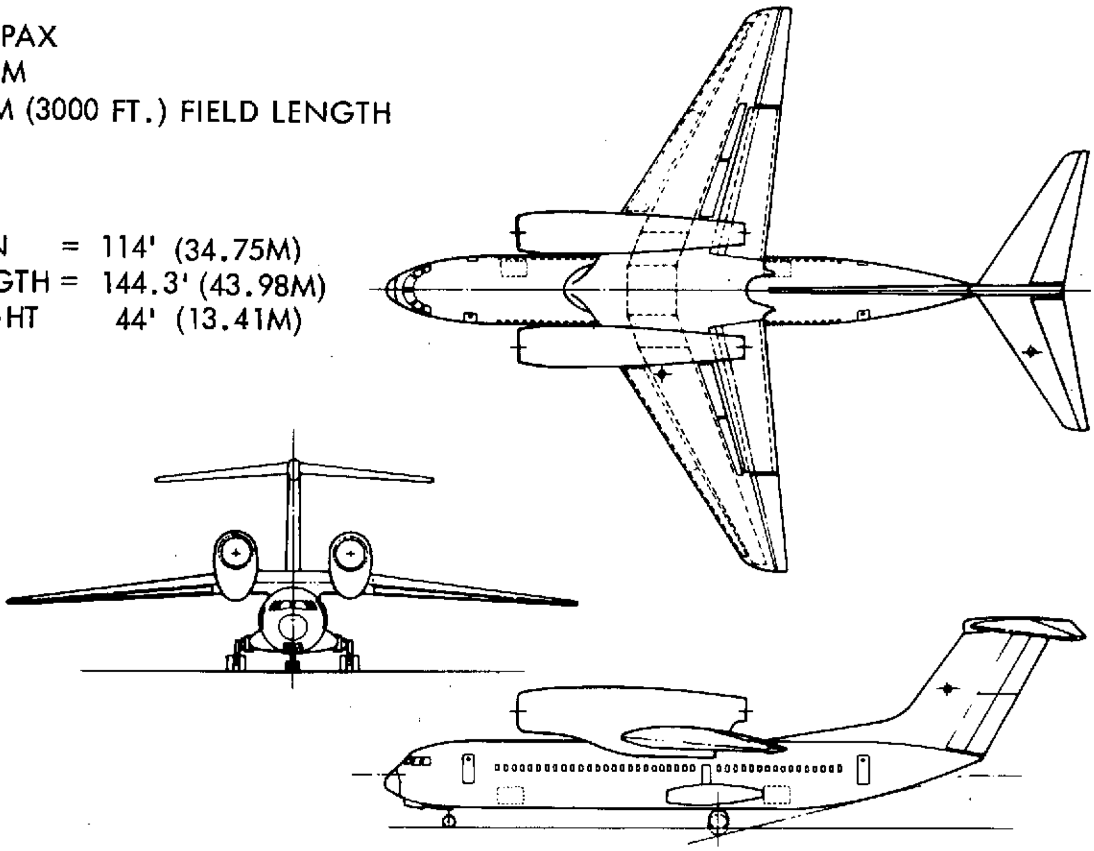
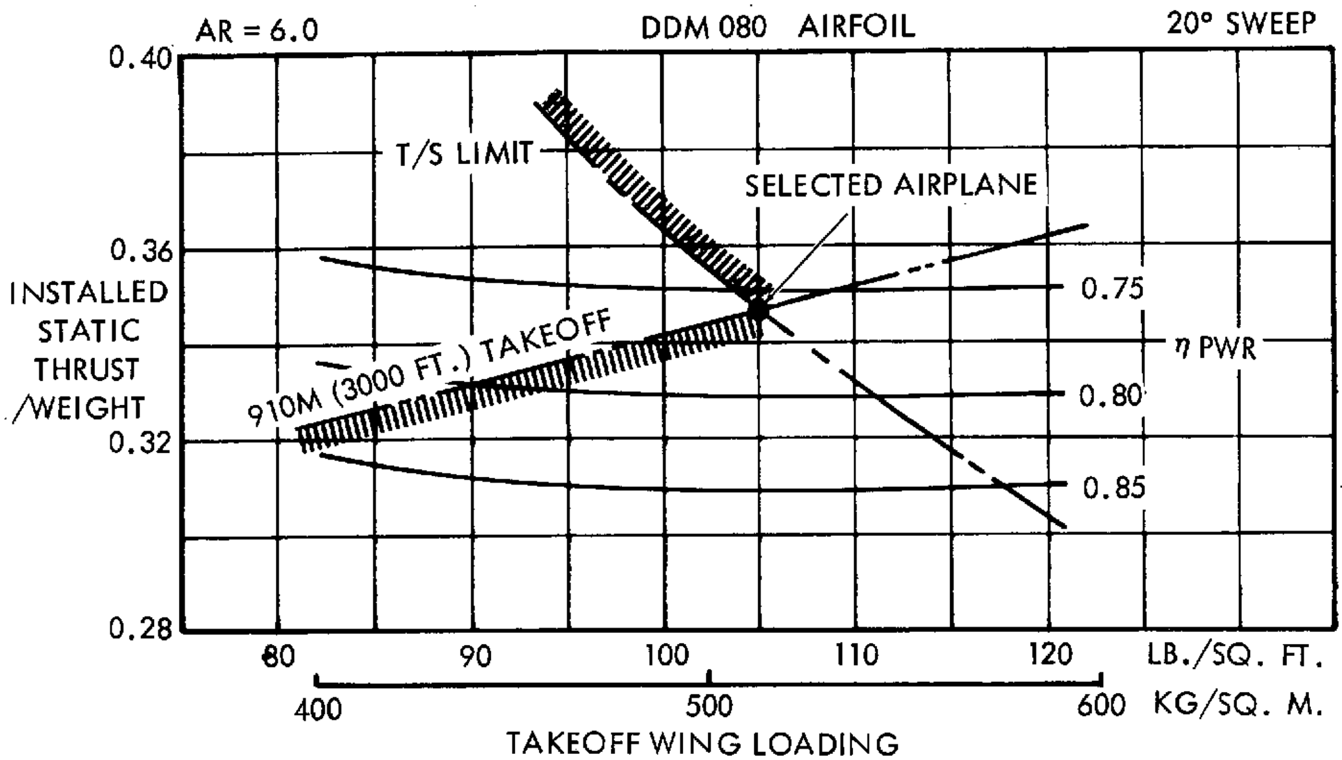


FIGURE 177: AW - GENERAL ARRANGEMENT, 2-ENGINE, FPR 3.0



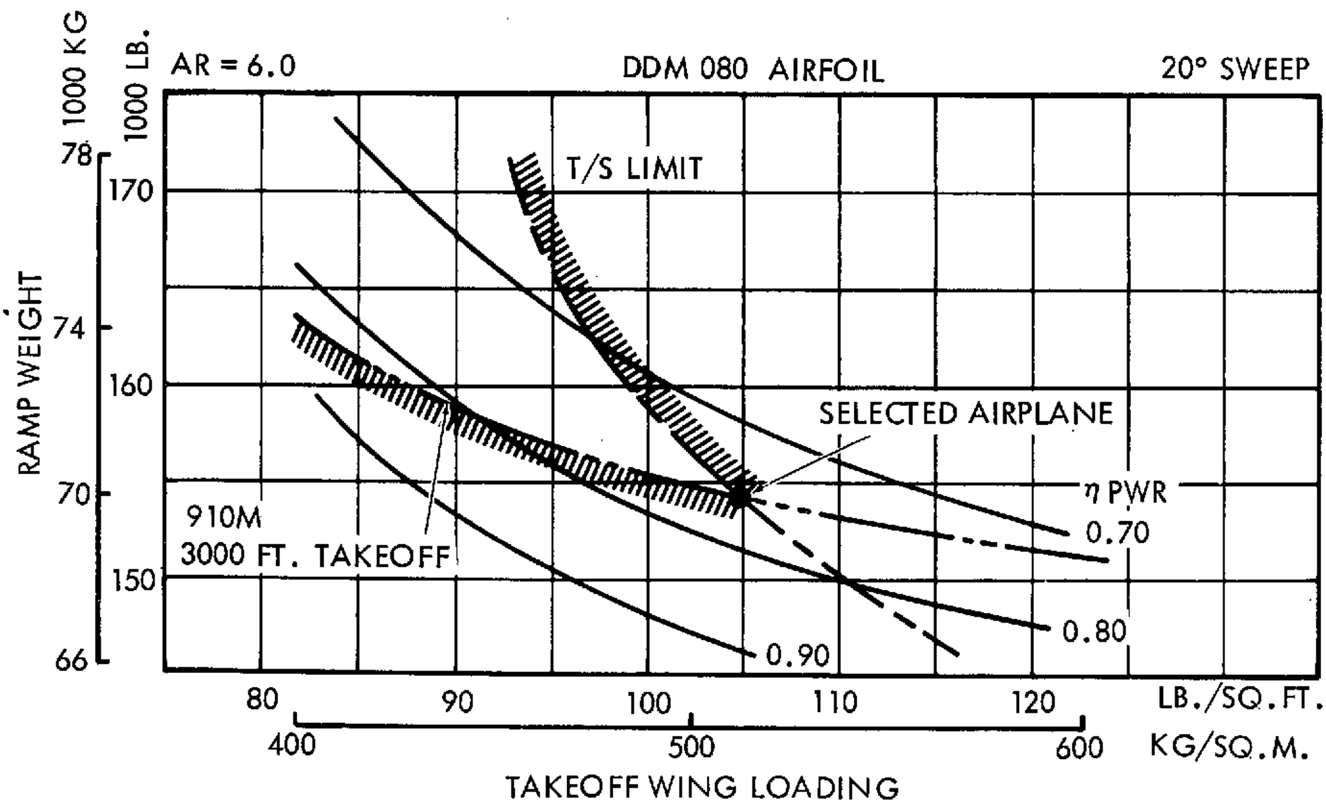


FIGURE 178: AW - T/W AND RAMP WEIGHT VS W/S (4 ENGINES)

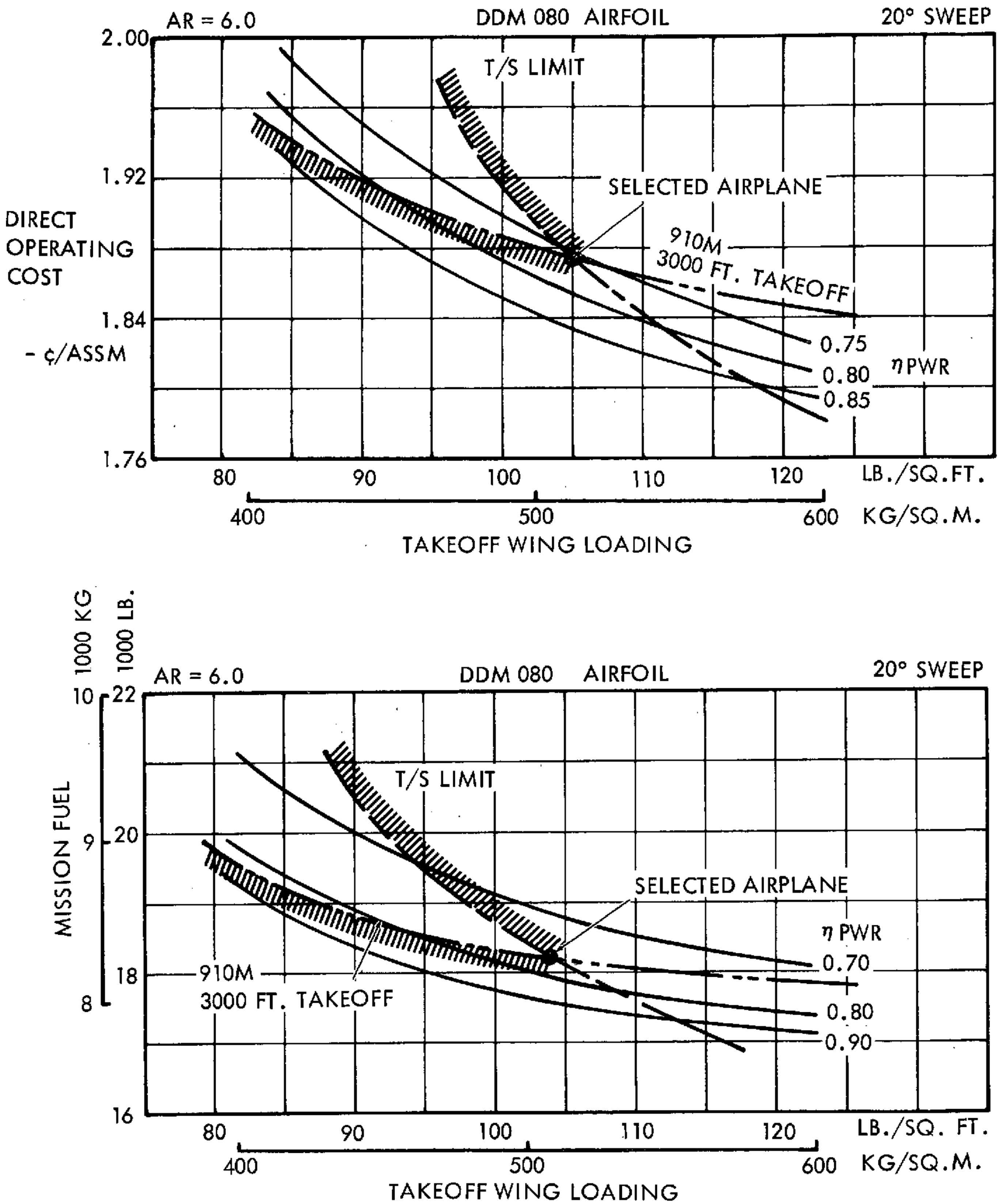


FIGURE 179: AW - DOC AND MISSION FUEL VS W/S (4 ENGINES)

148 PAX

0.8 M

910M (3000 FT.) FIELD LENGTH

SPAN = 28.85M (94.66')

LENGTH = 42.37M (139')

HEIGHT = 11.73M (38.5')

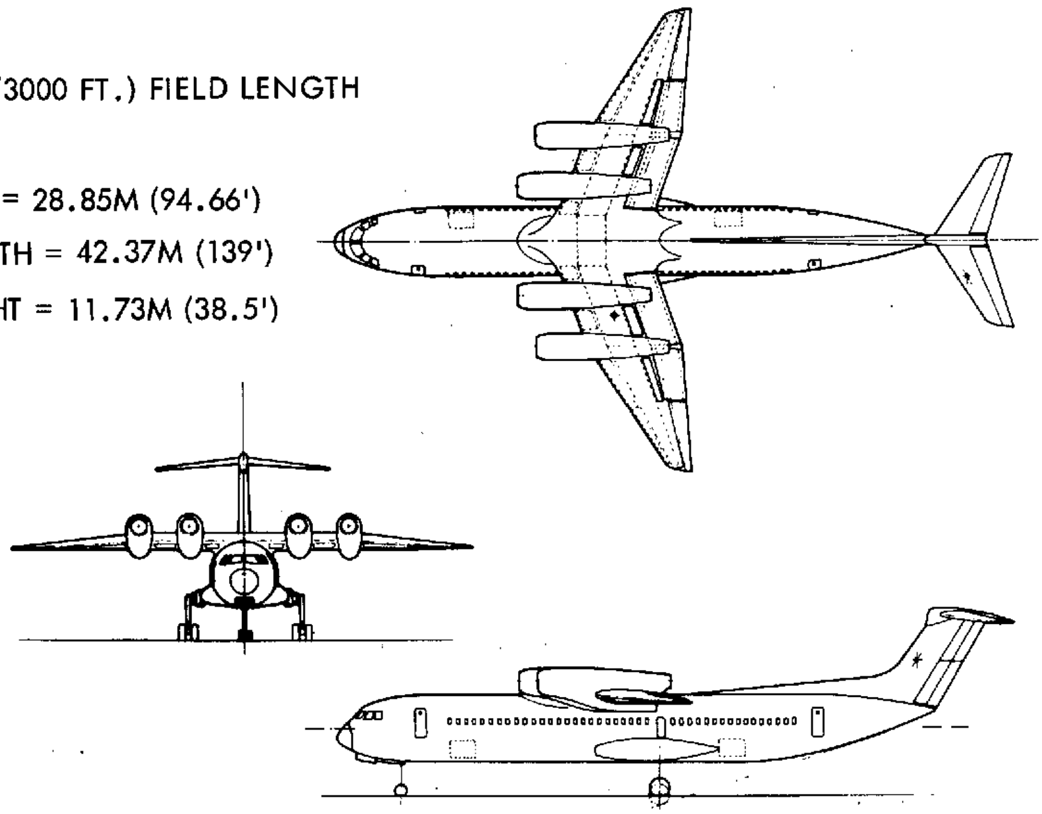


FIGURE 180: AW - GENERAL ARRANGEMENT, 4-ENGINE, FPR 3.0

TABLE XVI: BASELINE MISSION AW: PRINCIPAL CHARACTERISTICS

148 PAX; 910 m. (3000 FT.) FIELD LENGTH; FPR 3.0; 926 Km RANGE;
0.8 M @ 9140 m. (30,000 FT.)

	4 ENGINE	2 ENGINE
ASPECT RATIO	6.0	5.0
SWEEP ANGLE - DEG.	20	20
WING LOADING - Kg/m^2	513	369
- (LB/SQ.FT.)	(105.0)	(75.5)
INSTALLED T/W - N/Kg	3.40	4.36
- (LB/LB)	(0.347)	(0.444)
INSTALLED T/S - KN/m^2	1.75	1.60
- (LB/SQ.FT.)	(36.5)	(33.5)
RAMP GROSS WEIGHT - Kg	68,897	92,909
- (LB)	(154,097)	(204,829)
OPERATING WEIGHT EMPTY - Kg	45,265	63,572
- (LB)	(99,793)	(140,153)
RATED THRUST/ENGINE - KN	64.9	219.7
- (LB)	(14,586)	(49,397)
MISSION FUEL - Kg	8,266	11,705
- (LB)	(18,224)	(25,806)
AIRFRAME COST - $M	6.547	7.880
TOTAL ENGINE COST - $M	2.979	2.854
DOC - ¢/ASSM	1,876	2.164

Since the performance of the 2-engined AW configuration appears to be inferior, a check was made of the sizing methodology. The 2-engine MF configuration has been modified in steps until identical to the 2-engine AW configuration as shown in Table XVII. It appeared from this analysis that the increased ramp gross weight was due to the poor SFC of the AW engine and the increased weight of the wing, flap and ducting. Since neither the 2-engined nor the 4-engined MF airplanes are takeoff critical but are sized by cruise and landing requirements they would be expected to be similar in size and DOC. However, takeoff being critical in the case of the AW concept, the 4-engine configuration can achieve a higher wing loading and is, therefore, more economical in cruise which results in a smaller sized airplane.

In accounting for the poor performance of the 2-engine AW it has been realized that the basic C_L, C_X, C_T relationships in the STOL mode which were developed for reference 2 were based on NASA data at only 30° and 70° flap settings. In generating data for other flap settings it was assumed (based on both Lockheed and Boeing proposed flap mechanisms) that the augmentor opened during the first 25° of flap deflection. The augmentation ratio was therefore assumed to vary from 1.0 with the flap retracted to 1.4 with the augmentor fully deployed at 25° deflection. This has resulted in satisfactory 4-engine airplanes since the takeoff flap required is of the order of 25°. However, in the case of the 2-engined configurations, the optimum flap setting is only 7-1/2° and the augmentation from the data is then nearer 1.0 than 1.4. If the flap mechanism is designed to fully deploy the augmentor at very small flap deflections then it should be possible to obtain full augmentation which could result in a reduction of the (T/W) required which would improve the DOC to approximately 1.97¢/ASSM and the ramp gross weight would be reduced to 180,000 lb. To confirm this prediction, wind tunnel tests at small flap deflections would be necessary.

The engine pricing for the 2-engined configuration has been based on a production quantity of 750; if the pricing were to be based on 1500 engines, as for the 4-engined configuration, the DOC would reduce to 1.89 ¢/ASSM which is quite close to the 1.87 ¢/ASSM of the 4-engined configuration. However, it must be noted that the FPR 3.0 engine cannot be used for CTOL or other powered lift applications and the original engine pricing basis upon a fixed number of STOL aircraft sets is more realistic.

Configuration No.	MF ⇒ (1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	⇒ AW (10)
Configuration Change	MF Baseline	$W/S_{T.O}$	Λ, λ, DDM, V_H	Engine Data	Engine (η = .692)	Wing & Flap Weight	Duct Weight & Costs	Misc.	AR	Delete Conting.
Aspect Ratio	7.0	7.0	7.0	7.0	7.0	7.0	7.0		5.0	5.0
$W/S_{T.O.}$ - Lb/Sq. Ft.	58.8	67.8	67.8	69.5	68.7	68.7	69.0	68.7	75.5	75.5
Inst. T/W	.450	.428	.426	.280	.404	.391	.381	.378	.444	.444
FPR	1.35	1.35	1.35	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Wing Area - Sq. Ft.	2,511	2,013	2,048	2,193	2,553	3,017	3,436	3,477	2,749	2,683
OWE - Lb.	99,960	90,878	93,032	98,079	117,782	145,500	171,600	173,074	144,481	140,153
RGW - Lb.	148,379	137,325	139,730	153,529	177,142	209,285	239,426	241,215	209,852	204,829
Mission Fuel - Lb.	13,282	11,927	12,110	18,915	21,830	25,200	28,297	28,533	26,375	25,806
Single Engine Thrust - Lb.	36,412	32,041	32,501	23,474	38,992	44,570	49,636	49,726	50,657	49,397
A/F Price - $M	6.033	5.712	5.782	6.413	7.320	8.216	8.63	8.672	8.019	7.881
Tot. Eng. Price - $M	2.565	2.453	2.465	2.200	2.627	2.753	2.859	2.860	2.874	2.854
DOC - ¢/ASSM	1.685	1.600	1.616	1.791	1.975	2.185	2.344	2.355	2.198	2.164

TABLE XVII: AW - STEP BY STEP COMPARISON OF 2-ENGINED MF AND AW AIRPLANES

5.5 AW FUEL CONSERVATIVE VEHICLES

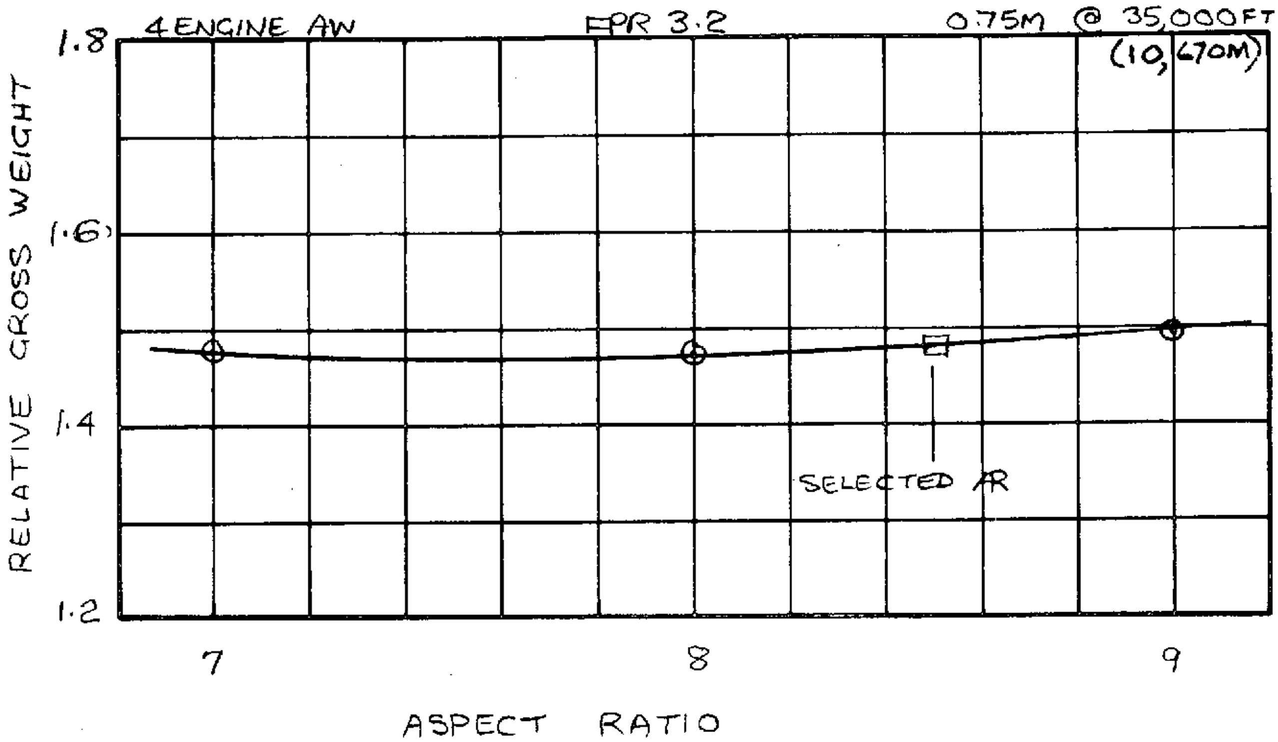
Whereas the configurations of the baseline mission AW vehicles previously described in Section 5.4 have been derived on the basis of minimizing DOC at a representative 1972 fuel price of 11.5¢/gallon, the effects of elevated fuel prices and the configuration of the AW vehicle for minimum mission fuel have subsequently been considered in conceptual design studies undertaken primarily for the QPLT program.

5.5.1 Orthodox AW Concept

Orthodox fuel-conservative AW vehicles which are conceptually identical with those described in Section 5.4 have been predicated upon the use of an engine that is representative of the Pratt and Whitney STF395D (BM-2) as already described in Section 5.2. This engine incorporates a Boeing cycle modification with reduced primary nozzle area for cruise operation and has a lower sfc than the FPR 3.0 QCSEE engine upon which the baseline mission vehicles are based. A preliminary assessment of a similar modification to the latter engine has been accomplished by Detroit-Diesel Allison (DDA) and indicates a correspondingly improved sfc but to a lesser degree. Accordingly, only vehicles with the STF395D (BM-2) are presented here.

The scope of the study has not permitted as rigorous a configuration optimization process for these vehicles as that accomplished for the OTW-IBF and MF vehicles and with particular regard to exact aspect ratios which define the absolute minimum fuel and absolute minimum cost vehicles and their exact correlation with the optimum altitude and cruise speed. Nevertheless, the matrix of mission parameters which has been explored is considered to have been of an adequate size to render such discrepancies trivial for the purposes of comparing lift concepts since the inferiority of the AW vehicle has been shown to be radically more pronounced than could be accommodated by any slight improvement which might be effected.

Figures 181 through 183 present the effect of aspect ratio upon vehicle size, mission fuel consumption and direct operating cost at a representative cruise Mach No. (0.75) and an initial cruise altitude of 10,670m. (35,000 ft.) as determined by vehicle sizing



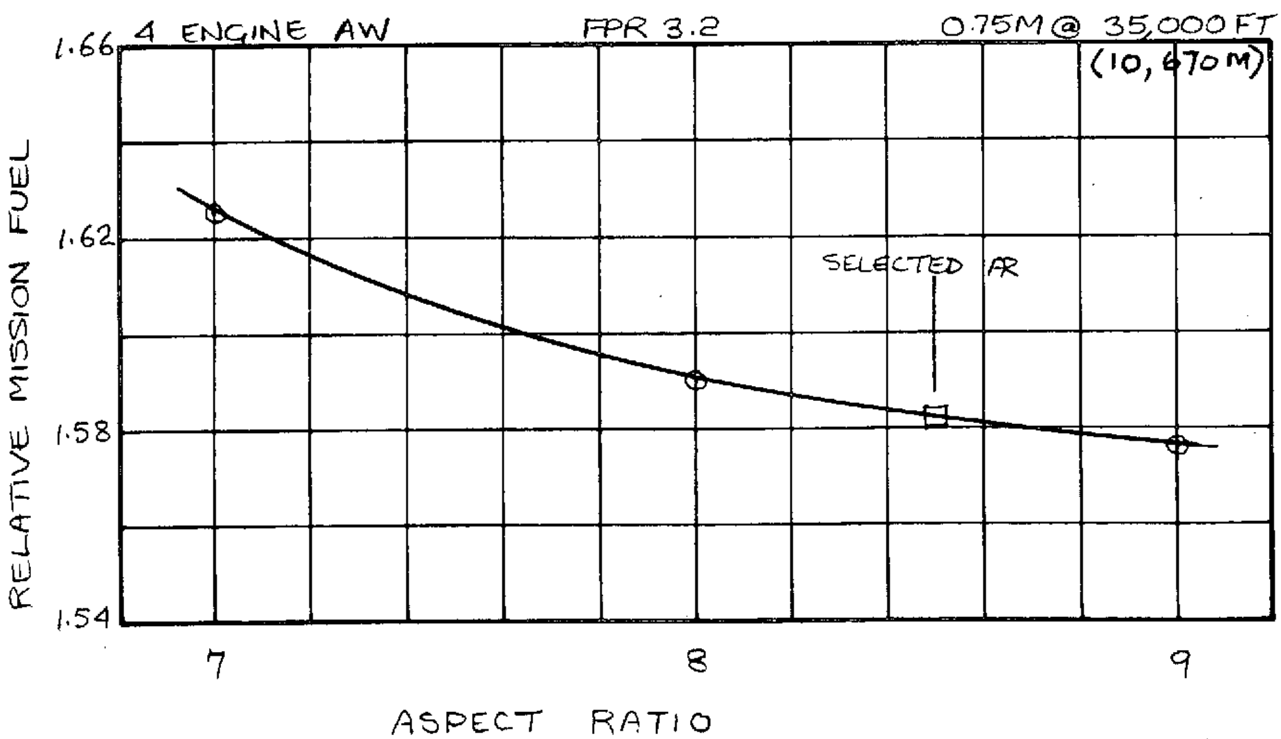
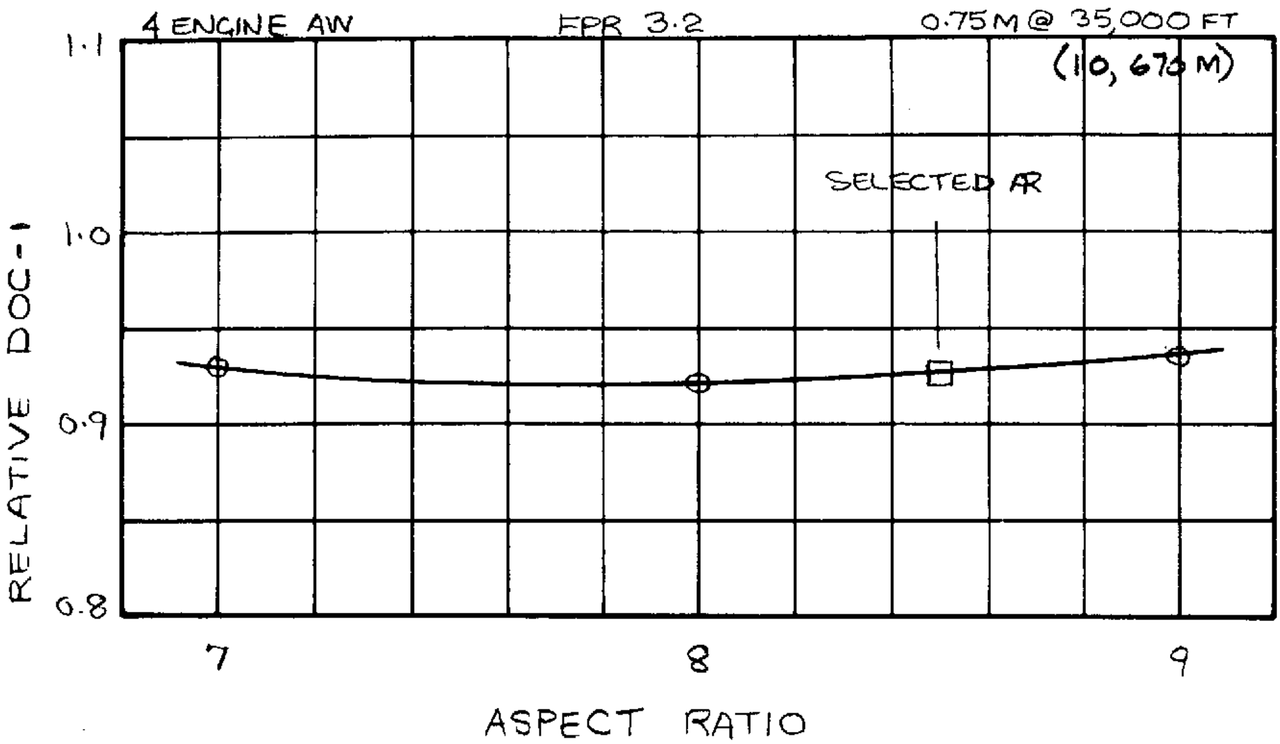


FIGURE 181: ORTHODOX AW: GROSS WEIGHT AND MISSION FUEL VS ASPECT RATIO



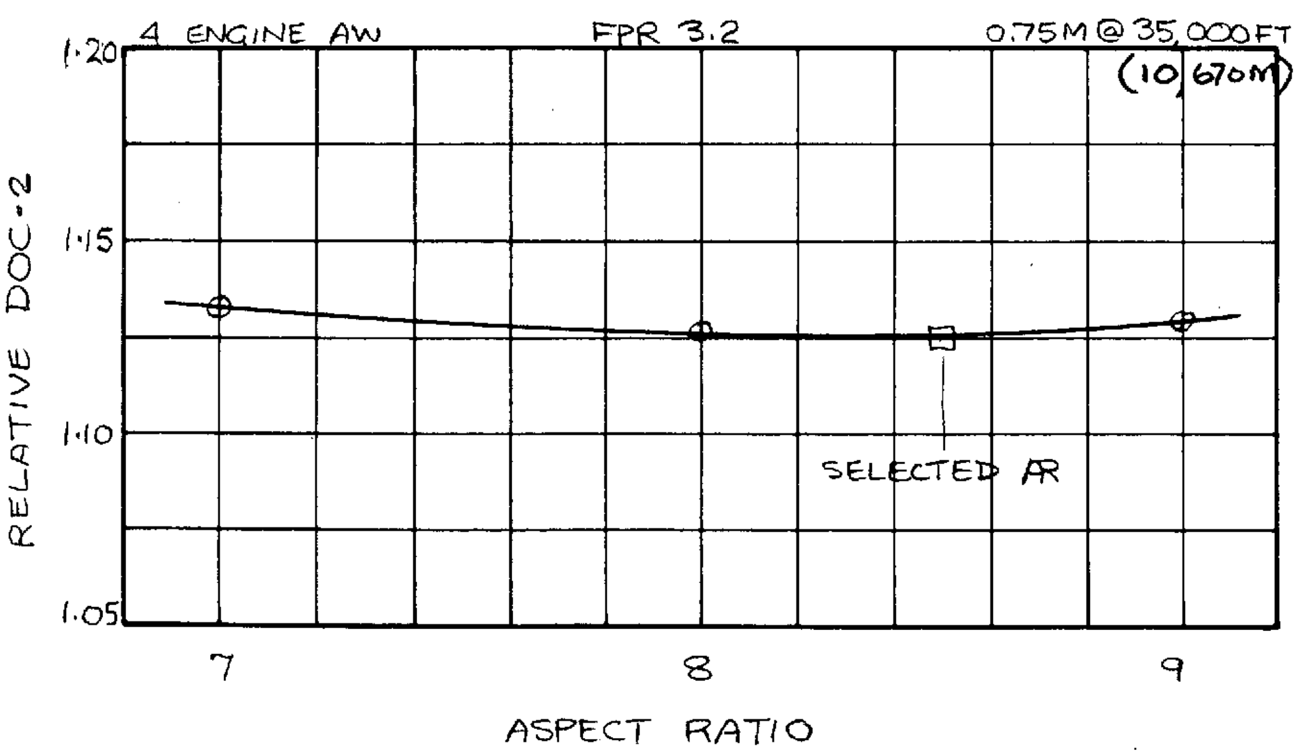
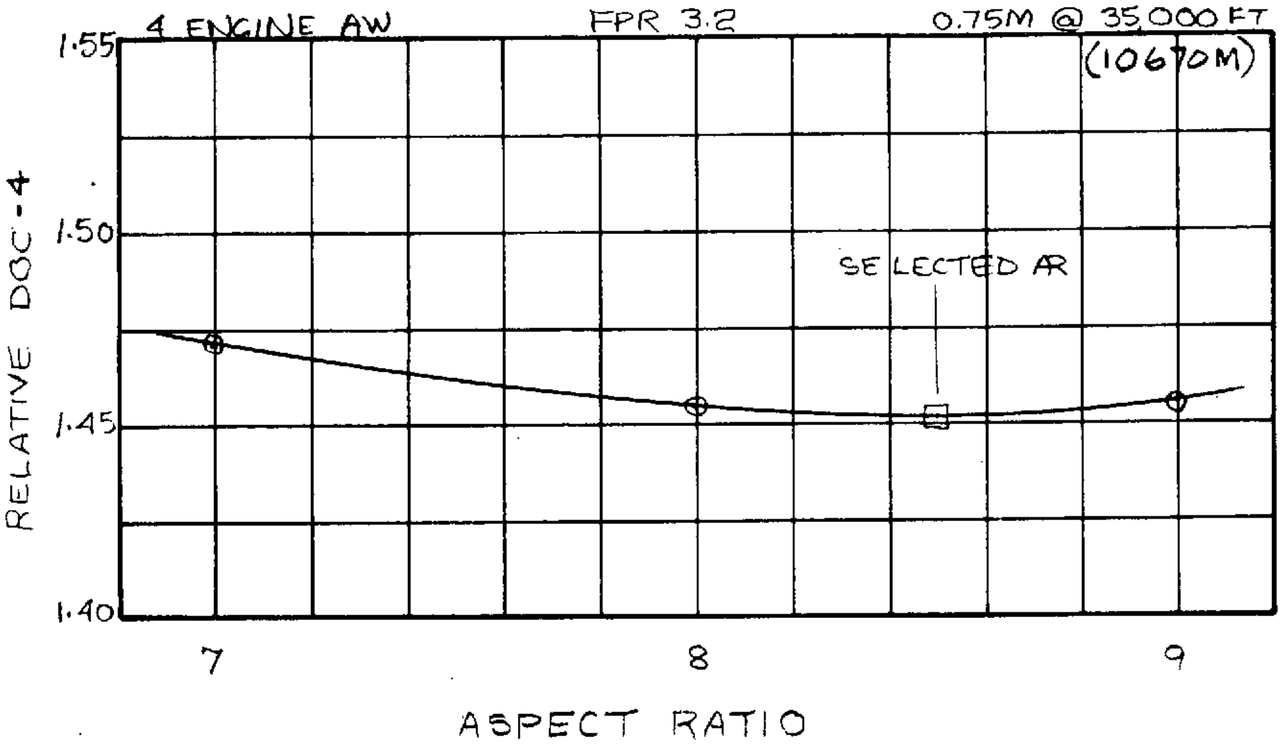


FIGURE 182: ORTHODOX AW: DOC-1 AND DOC-2 VS ASPECT RATIO



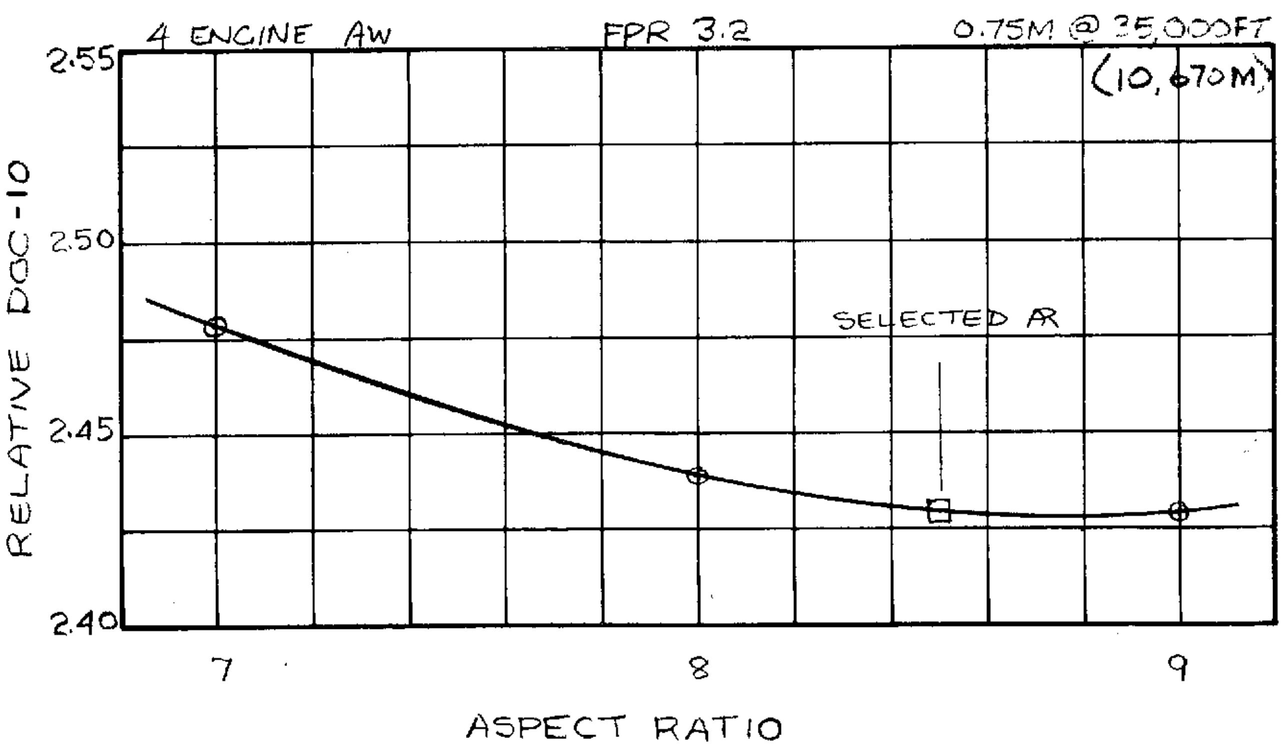
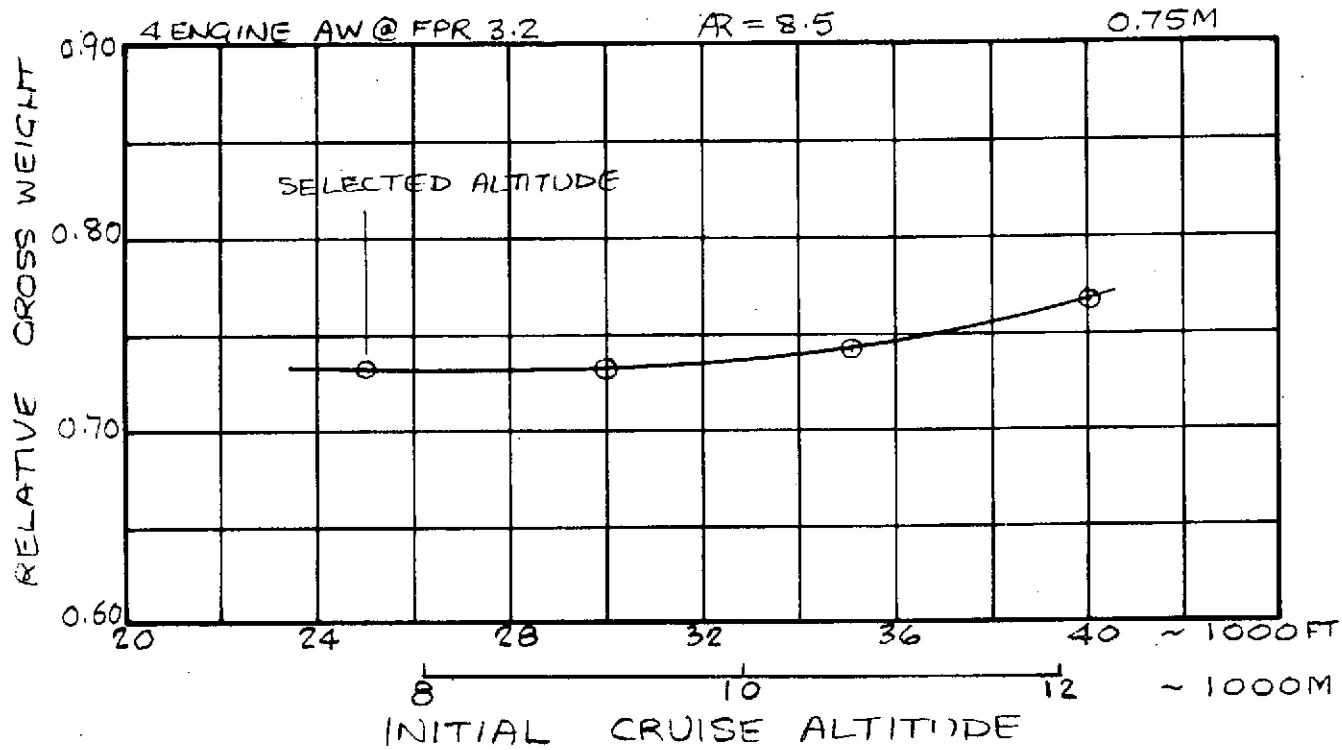


FIGURE 183: ORTHODOX AW: DOC-4 AND DOC-10 VS ASPECT RATIO

programs. DOC data is presented for nominal 1972 fuel prices (i.e. 11.5¢/gallon) and multiples of that base price as denoted by subscripts, e.g. DOC^{-4} -- 4 x base fuel price. Thus, the effect of conjectural developments in future fuel prices may be examined. Using twice the base fuel price as the basis for cost estimation, the least-cost airplane has an aspect ratio of approximately 8.5. This aspect ratio is also near optimum for minimum-fuel consumption configurations since the curves indicate that higher aspect ratios are unlikely to reduce mission fuel significantly (because of the increasingly severe T/S limit incurred).

Figures 184 through 186 present similar data for Mach 0.75 cruise as a function of initial cruise altitude at the selected aspect ratio of 8.5. It is shown that the least cruise altitude considered, i.e. 7620m. (25,000 ft.) minimizes the mission fuel and that, although absolute minimum DOC is attained at some slightly lower altitude, the scope for improvement is marginal.

On the basis of the initially selected aspect ratio (8.5) and the preferred cruise altitude of 7620m. (25,000 ft.) indicated in the foregoing data, the preferred cruise speeds for minimum DOC -2 and minimum mission fuel have been defined by extending the data to speeds above and below Mach 0.75. Previously acquired data points have also been included in the band of altitudes represented in Figures 187 through 189 which illustrate the overall effect of both cruise Mach No. and altitude on DOC and mission-fuel selection criteria. It is shown that mission fuel is minimized in the region of Mach 0.7 at 7620m. (25,000 ft.) but that minimum DOC-2 is obtained at a slightly higher speed (0.73M) at the same altitude. Since the distinction between operating costs at any speed in the bracket 0.70M - 0.75M is trivial, the latter speed was chosen for sizing specific vehicles at engine fan pressure ratios of 3.2 and 3.0. The influence of the relatively more severe T/S limit at FPR 3.0 (despite the small differential from 3.2) was made apparent in a 5 lb/sq. ft. reduction in wing loading of the selected FPR 3.0 airplane. A part-power cruise technique was indicated in either case for the selected cruise altitude 7620m. (25,000 ft.) but there was sufficient reserve power for either vehicle to cruise at substantially higher altitudes as desirable for flexible commercial operation.



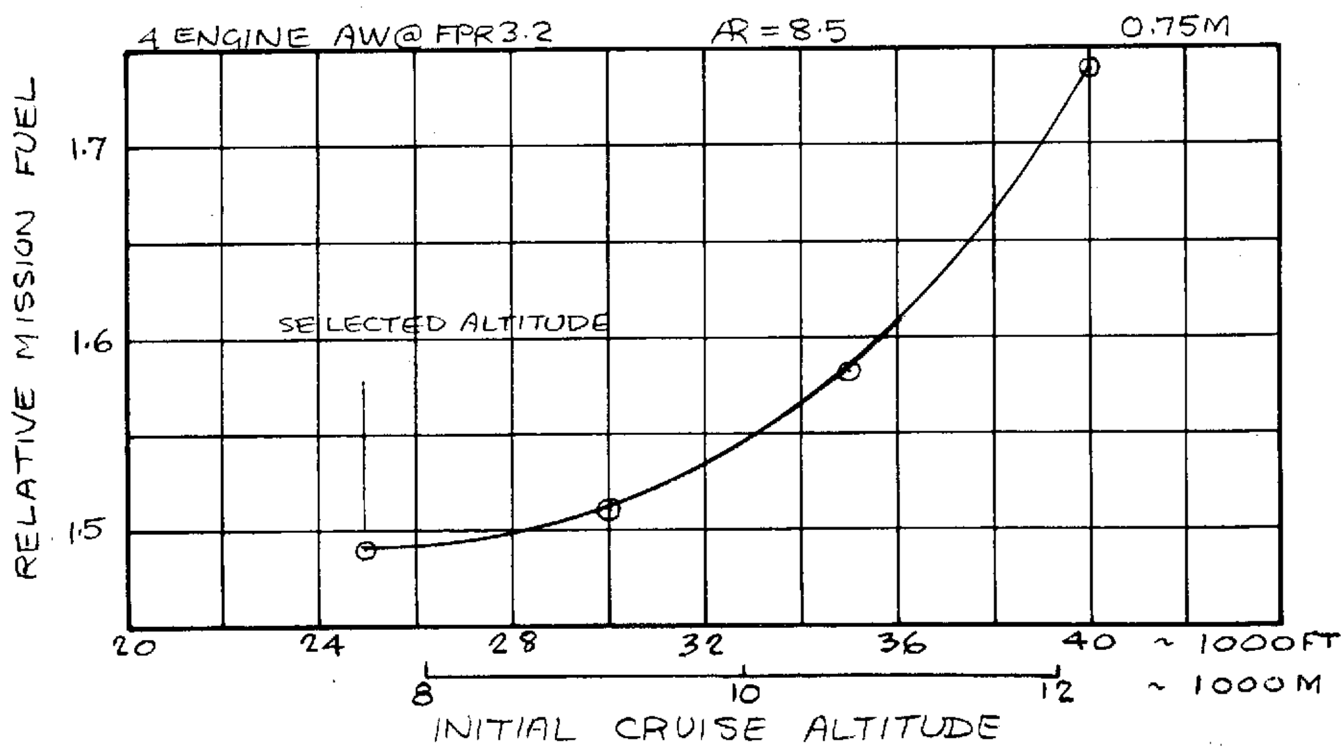
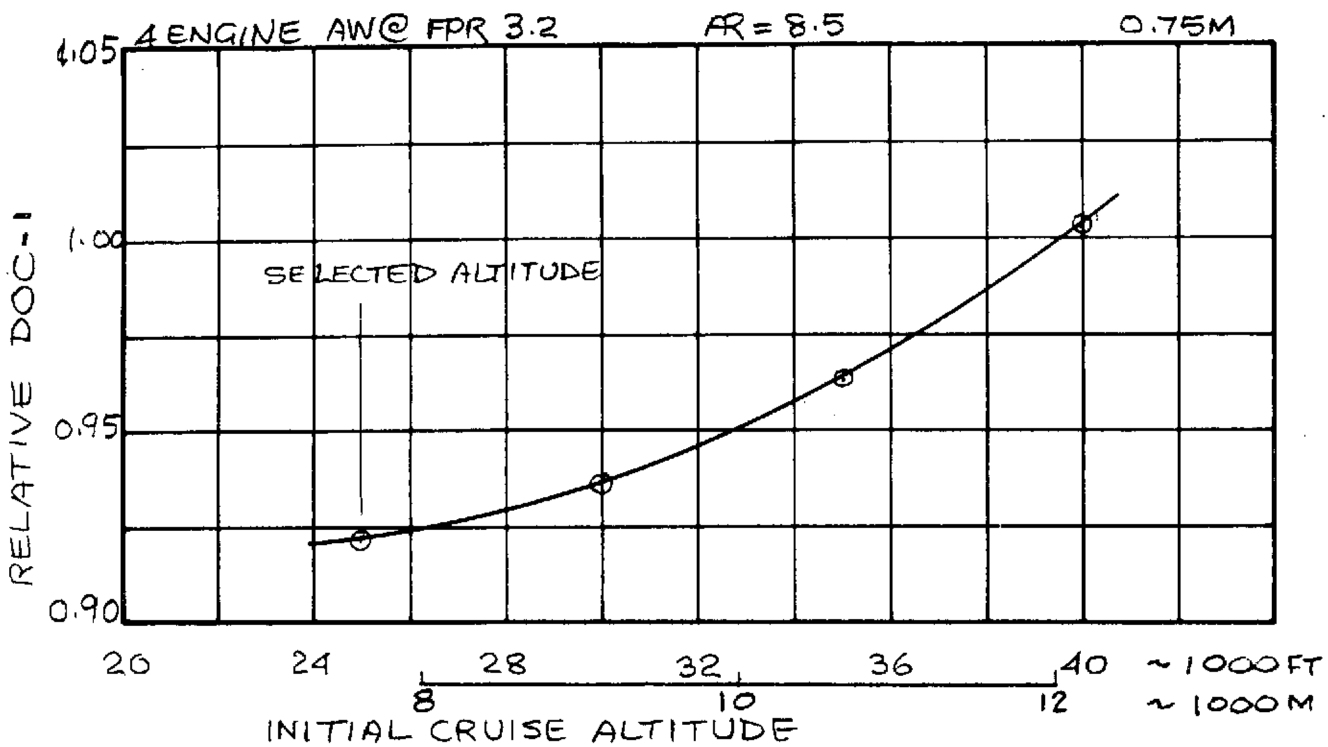


FIGURE 184: ORTHODOX AW: GROSS WEIGHT AND MISSION FUEL VS CRUISE ALTITUDE



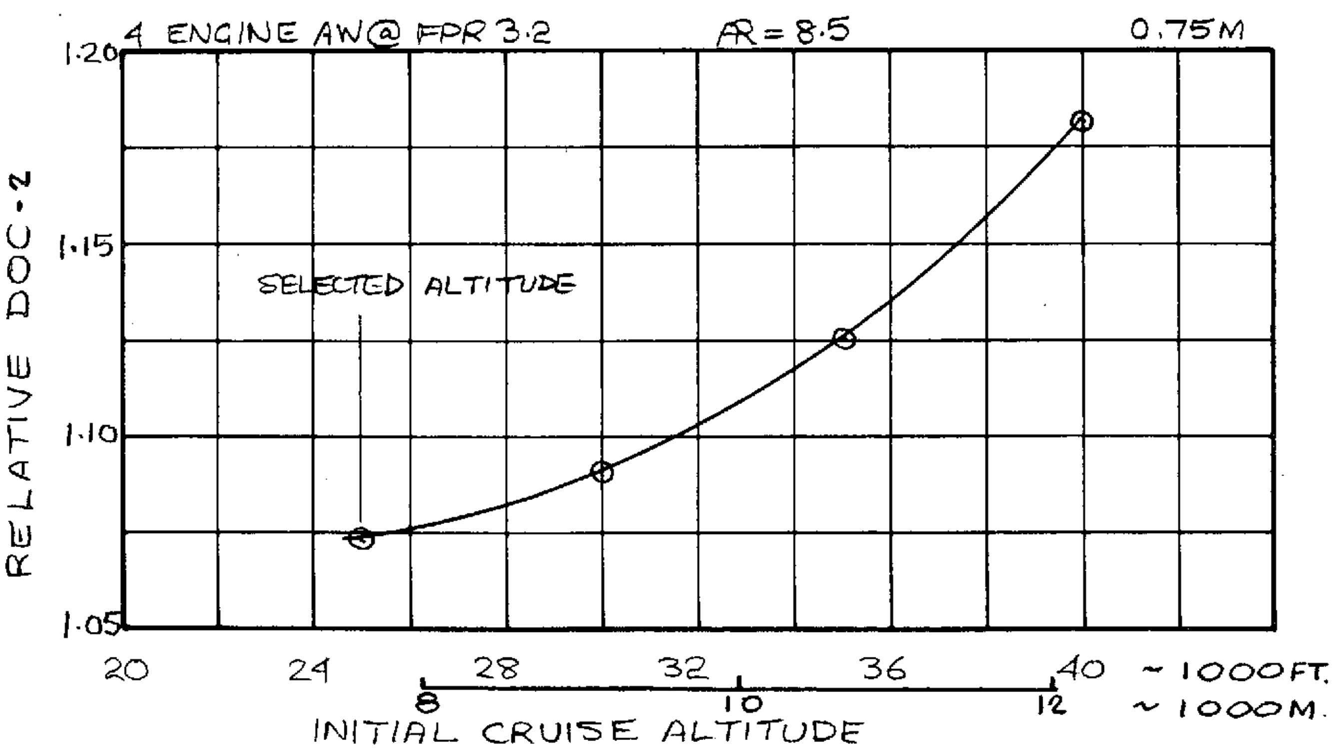
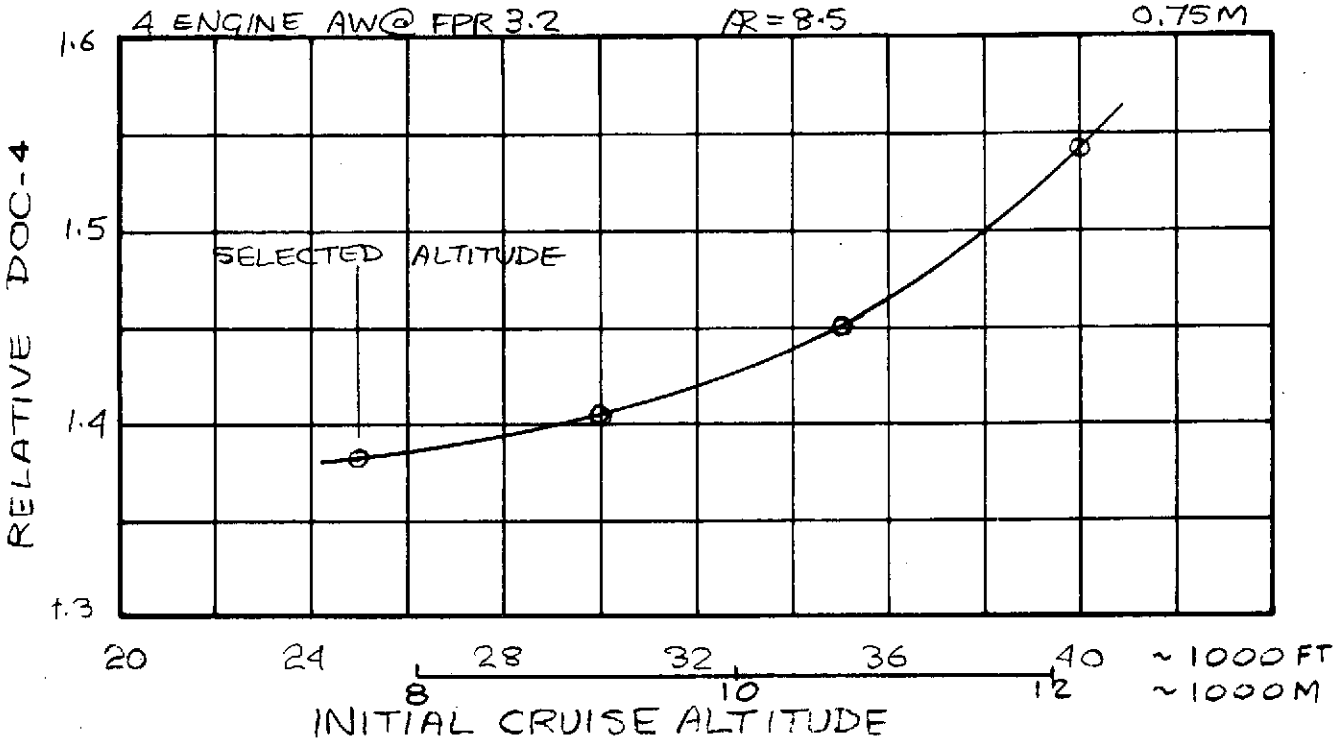


FIGURE 185: ORTHODOX AW: DOC-1 AND DOC-2 VS CRUISE ALTITUDE



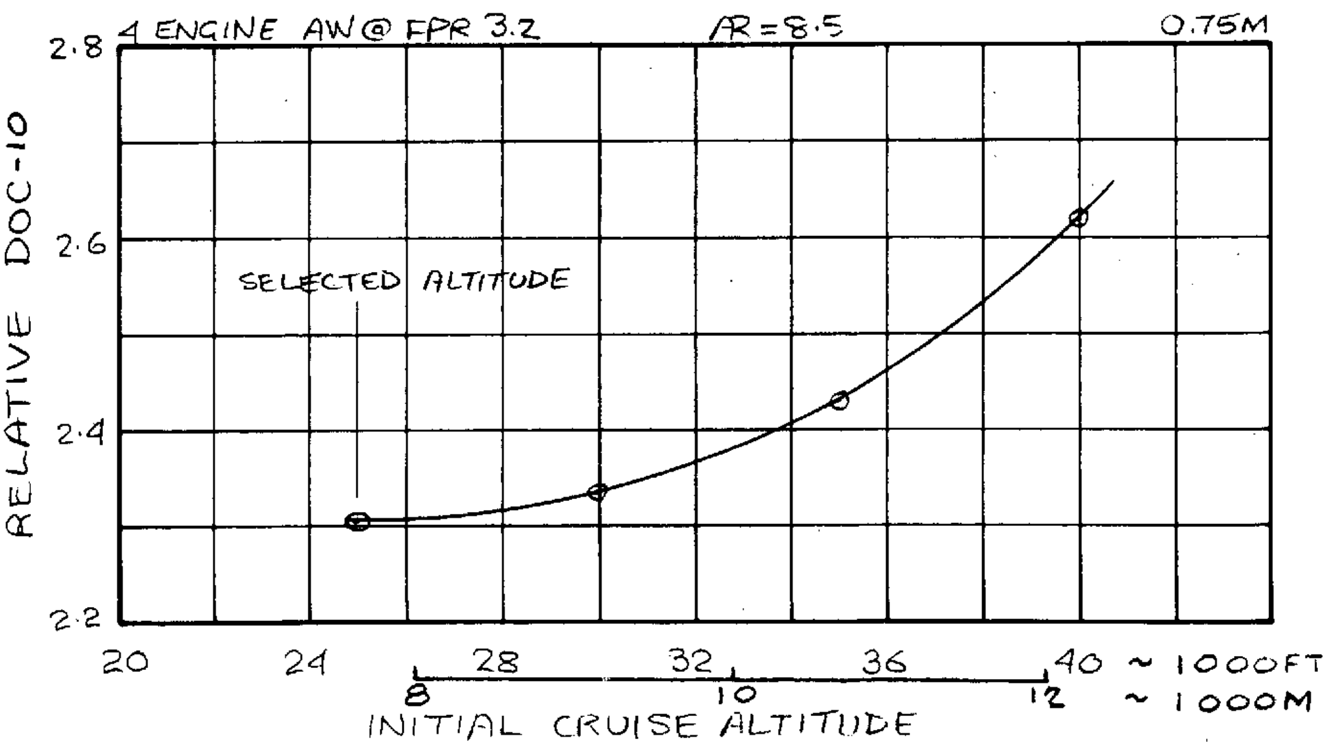
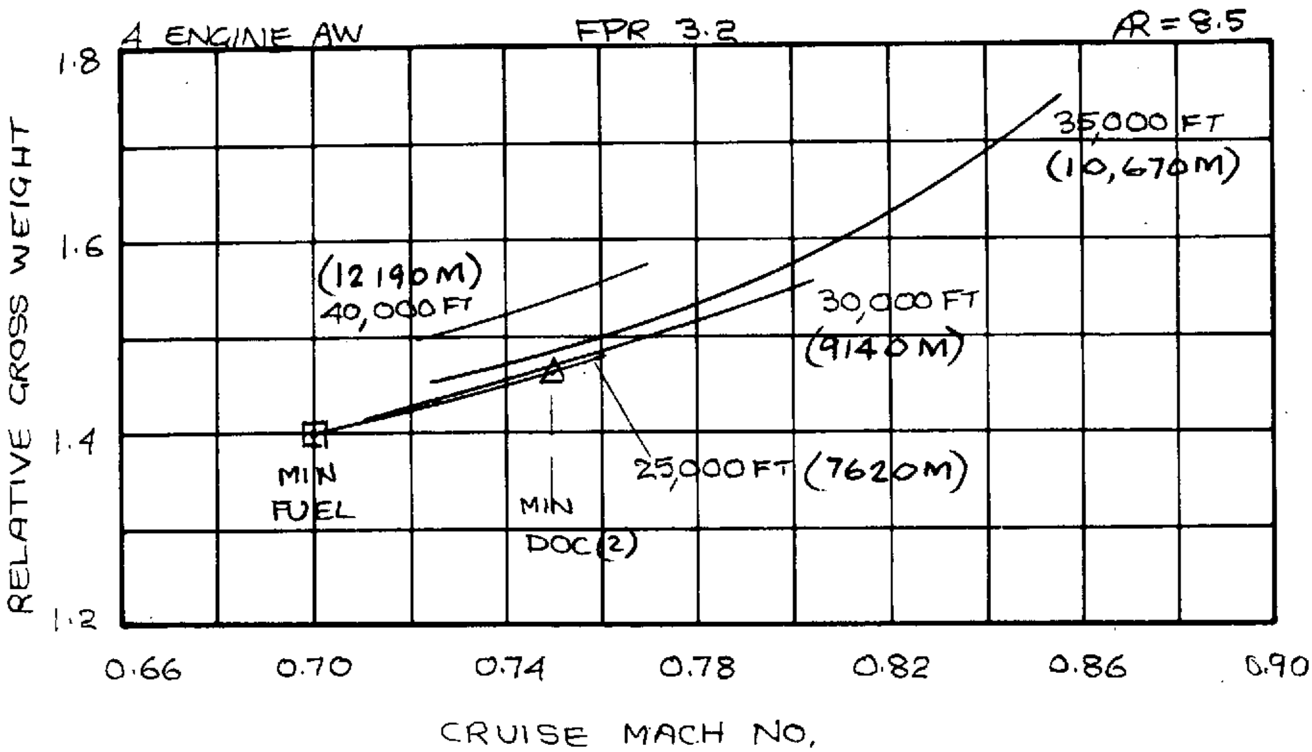


FIGURE 186: ORTHODOX AW: DOC-4 AND DOC-10 VS CRUISE ALTITUDE



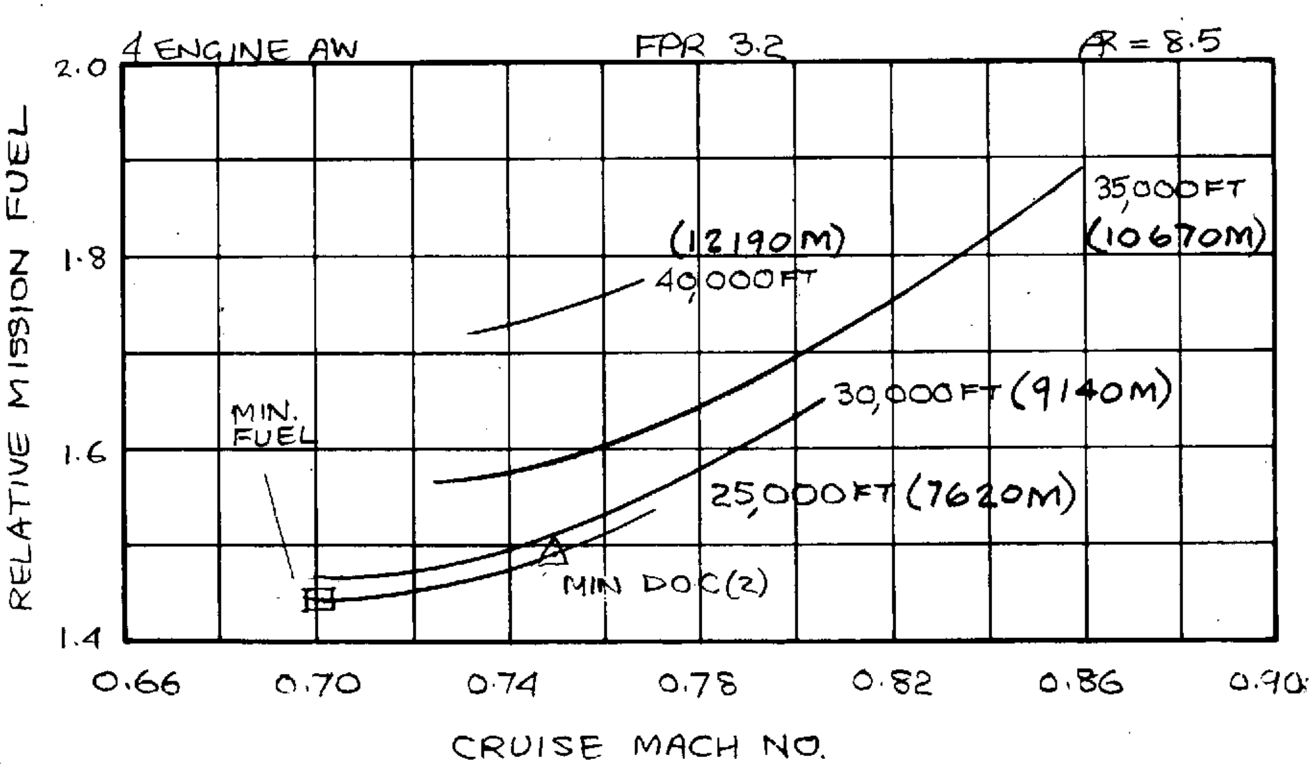
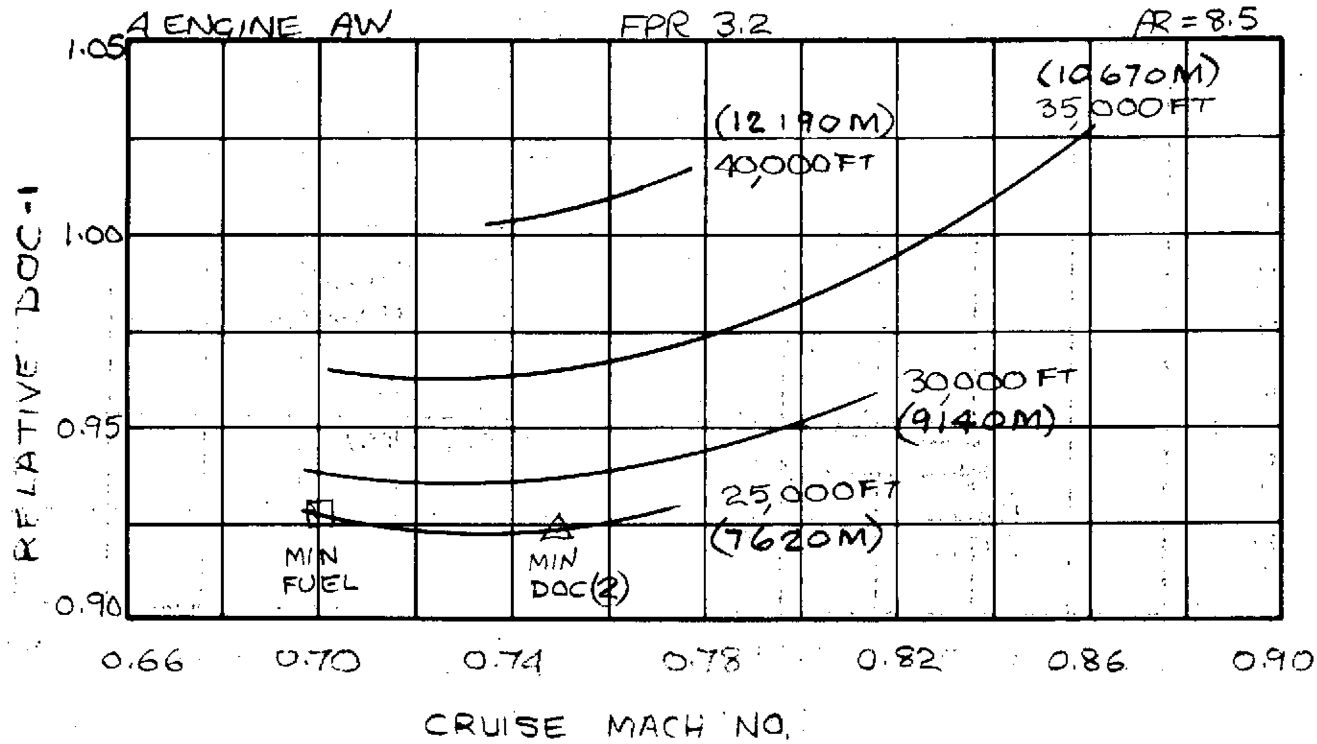


FIGURE 187: ORTHODOX AW: GROSS WEIGHT AND MISSION FUEL VS CRUISE SPEED



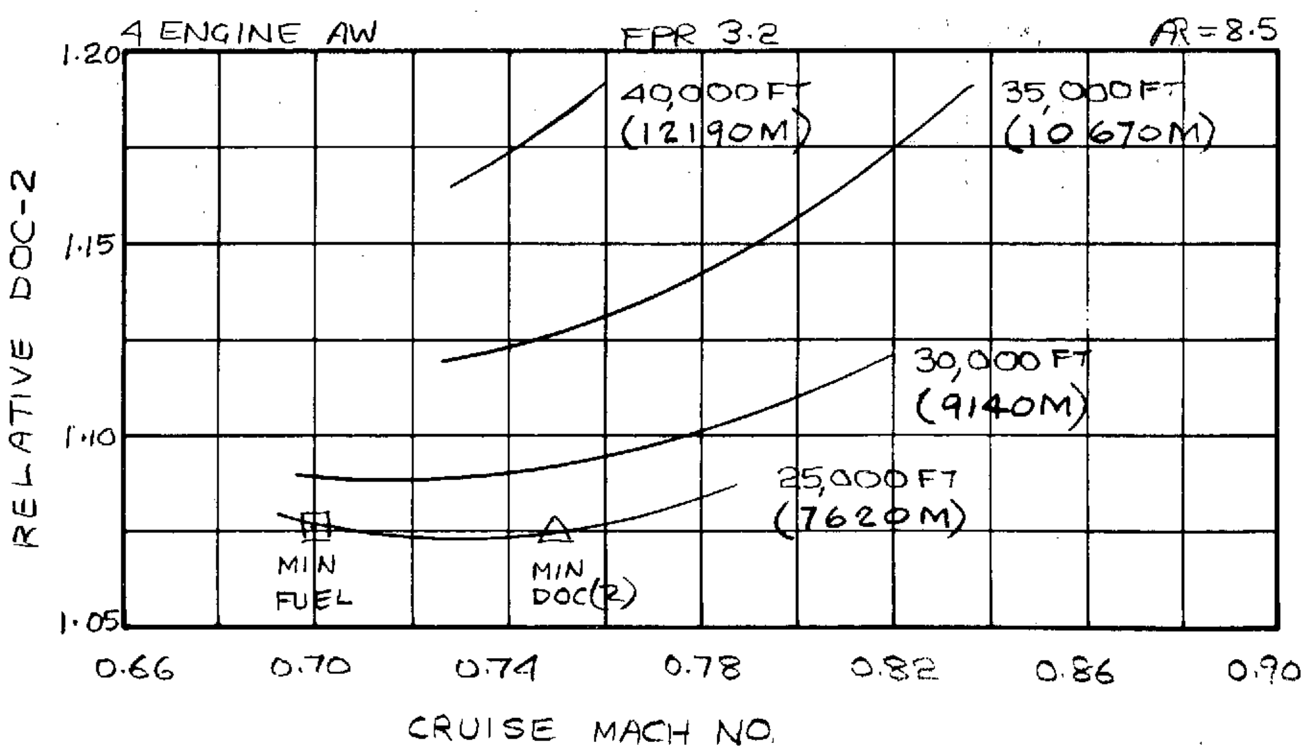
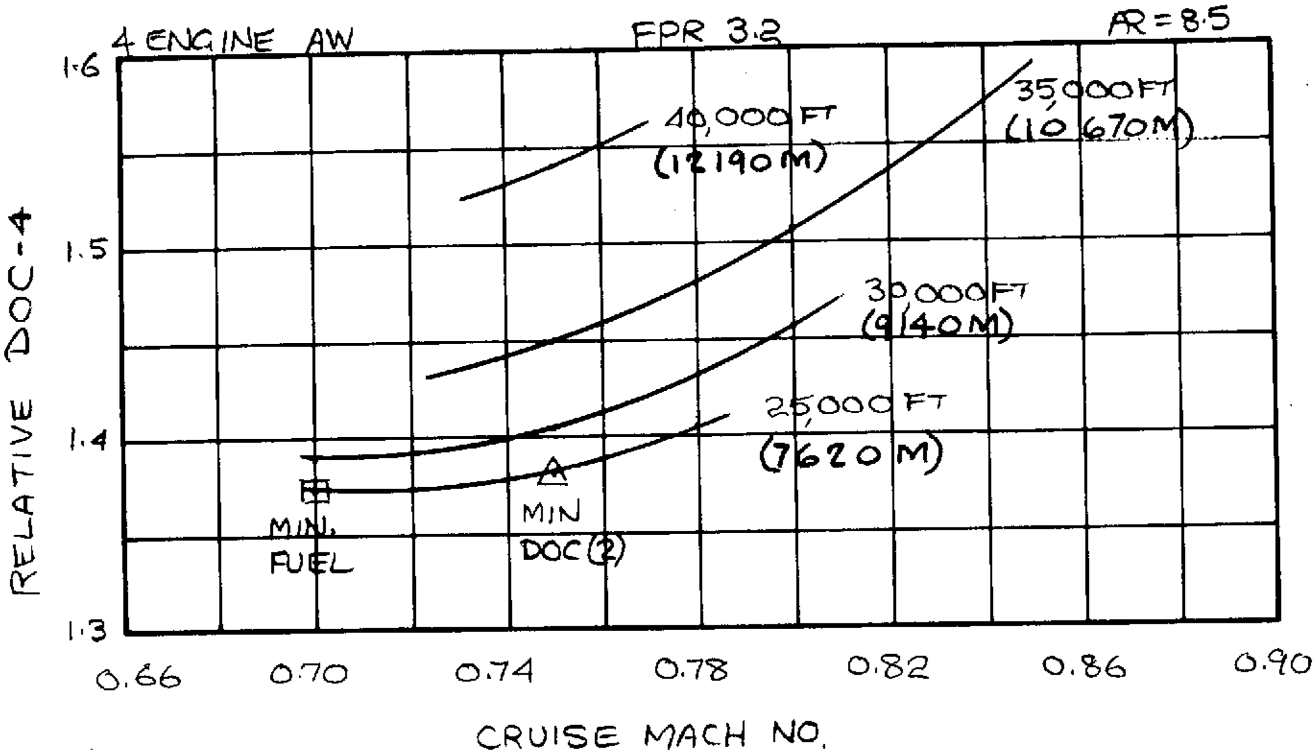


FIGURE 188: ORTHODOX AW: DOC-1 AND DOC-2 VS CRUISE SPEED



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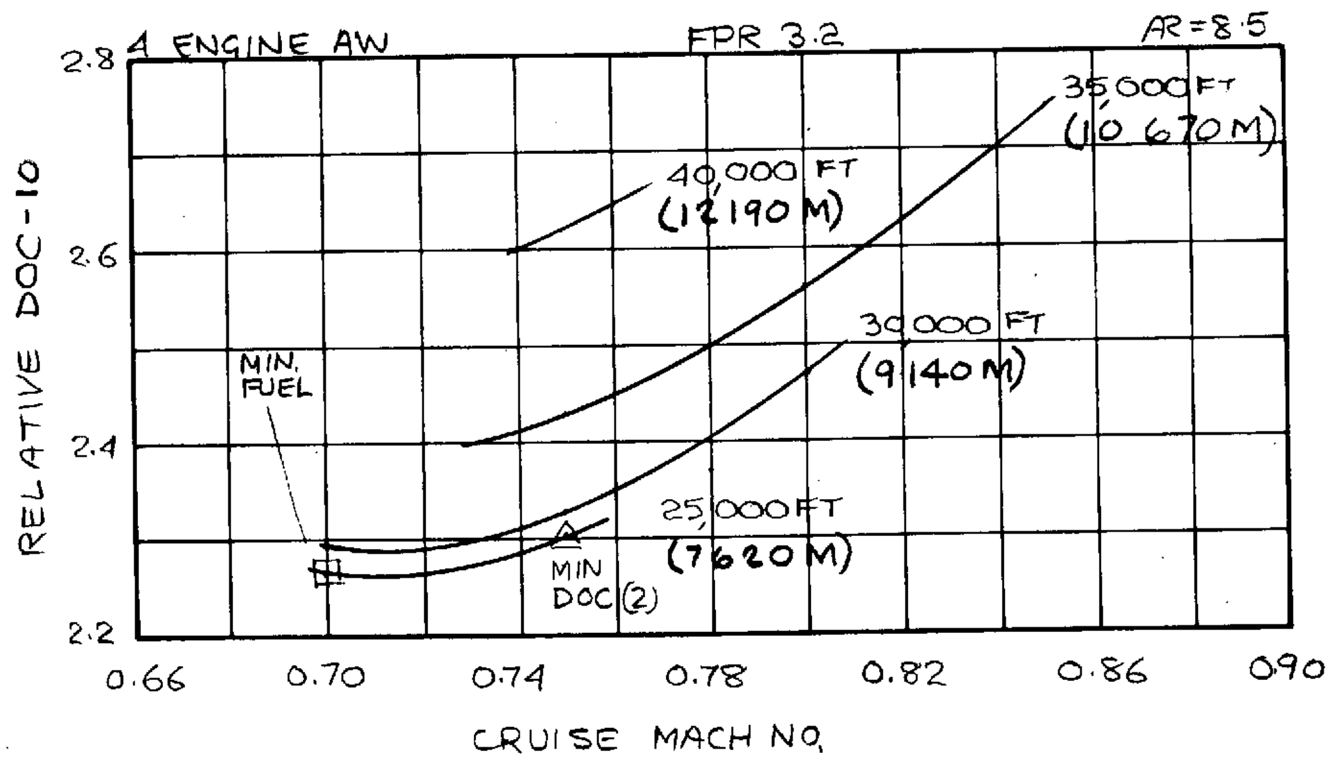


FIGURE 189: ORTHODOX AW: DOC-4 AND DOC-10 VS CRUISE SPEED

The principal characteristics of the selected fuel conservative vehicles for alternately minimum DOC-2 and minimum mission fuel are presented in Table XVIII Figure 190 presents a 3-view of the former vehicle which is also representative of the configuration of the latter.

5.5.2 Load Compressor AW Concept

The load compressor AW concept seeks to combine the low sfc, high thrust altitude lapse rate, and inherently low noise level of the low FPR engine for propulsion with the high lift capabilities of the orthodox AW concepts using a high pressure ratio air source for the purpose. It was initially surmised that first cost and maintenance costs would preclude the effective use of more than a total of four engines. Hence, initial conceptual studies have been based upon a combination of two FPR 1.35 propulsion engines and two FPR 3.0 load-compressors.

Superficially, the use of two distinct types of engine in this concept affords the optimization process a further degree of freedom which requires sub-optimization of the thrust-split between the two engines. However, in practice this degree of freedom effectively permits a thrust-split to be chosen which will simultaneously yield a full power cruise technique and high cruise wing loading. Figures 191 and 192 present the range of takeoff performance options for particular aspect ratios 10.0 and 14.0 in terms of the total installed thrust-weight ratio and as a function of wing loading and the split between AW load-compressor thrust and cruise engine thrust for four-engine vehicles. The overall T/S limit for a given cruise altitude and speed (which define wing thickness) is superposed on this figure and defines an upper bound to the attainable wing loading. This bound will generally be associated with the minimum-fuel vehicle and therefore a single ("optimum") takeoff T/W vs W/S relationship is derived and can be matched with the cruise requirements, i.e. the thrust split falls out.

Figures 193 through 195 present the effect of cruise altitude and aspect ratio upon vehicle size, mission fuel and DOC for the 926 Km. (500 n.mi.) mission previously described and a Mach 0.75 cruise speed. It will be noted that the initial cruise altitude

TABLE XVIII: PRINCIPAL CHARACTERISTICS OF ORTHODOX AW (148 PASS. @ 926 Km (500 N.M.) RANGE @ 910m (3000 FT) FIELD)

Optimization Basis		Min. DOC-2	Min. Fuel
Fan Pressure Ratio		3.2	3.2
No. Engines		4	4
Cruise Mach No.		0.75	0.70
Initial Cruise Altitude	m	7620	7620
	(ft)	25,000	25,000
Aspect Ratio @ Sweep	(Deg.)	8.5 @ 10°	8.5 @ 10°
Takeoff Wing Loading	Kg/m^2	491	515
	(lb/sq ft)	100.5	105.5
Takeoff Thrust/Weight	N/kg	2.99	3.03
	(lb/lb)	0.305	0.309
Uninstalled Thrust/Eng.	KN	51.82	50.49
	(lb)	11,650	11,350
Wing Area	m^2	130.5	118.3
	(sq ft)	1405	1273
Ramp Gross Weight	Kg	63,458	60,977
	(lb)	139,900	134,431
Operating Weight Empty	Kg	40,891	39,988
	(lb)	90,150	88,159
Mission Fuel	Kg	6,559	6,330
	(lb)	14,460	13,956
DOC (1)	¢/ASSM	1.802	-
(2)	¢/ASSM	2.110	2.115
(4)	¢/ASSM	2.700	-
(10)	¢/ASSM	4.491	-

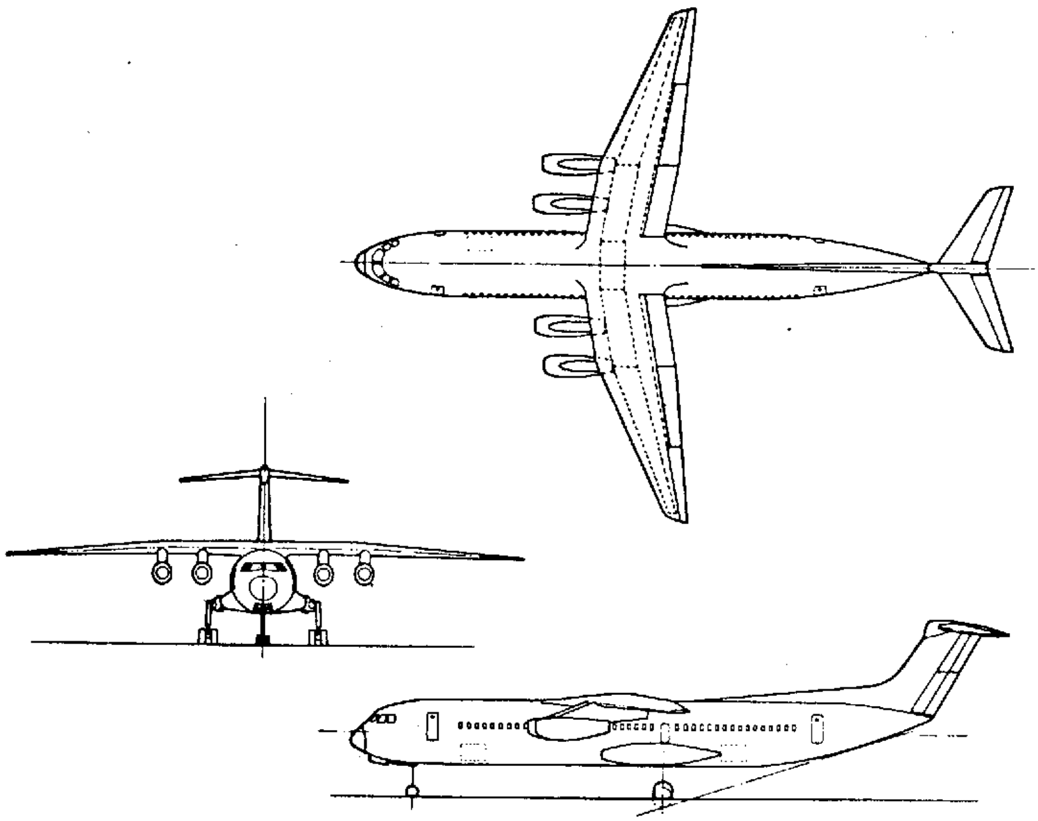


FIGURE 190: ORTHODOX AW: GENERAL ARRANGEMENT (FPR 3.2)

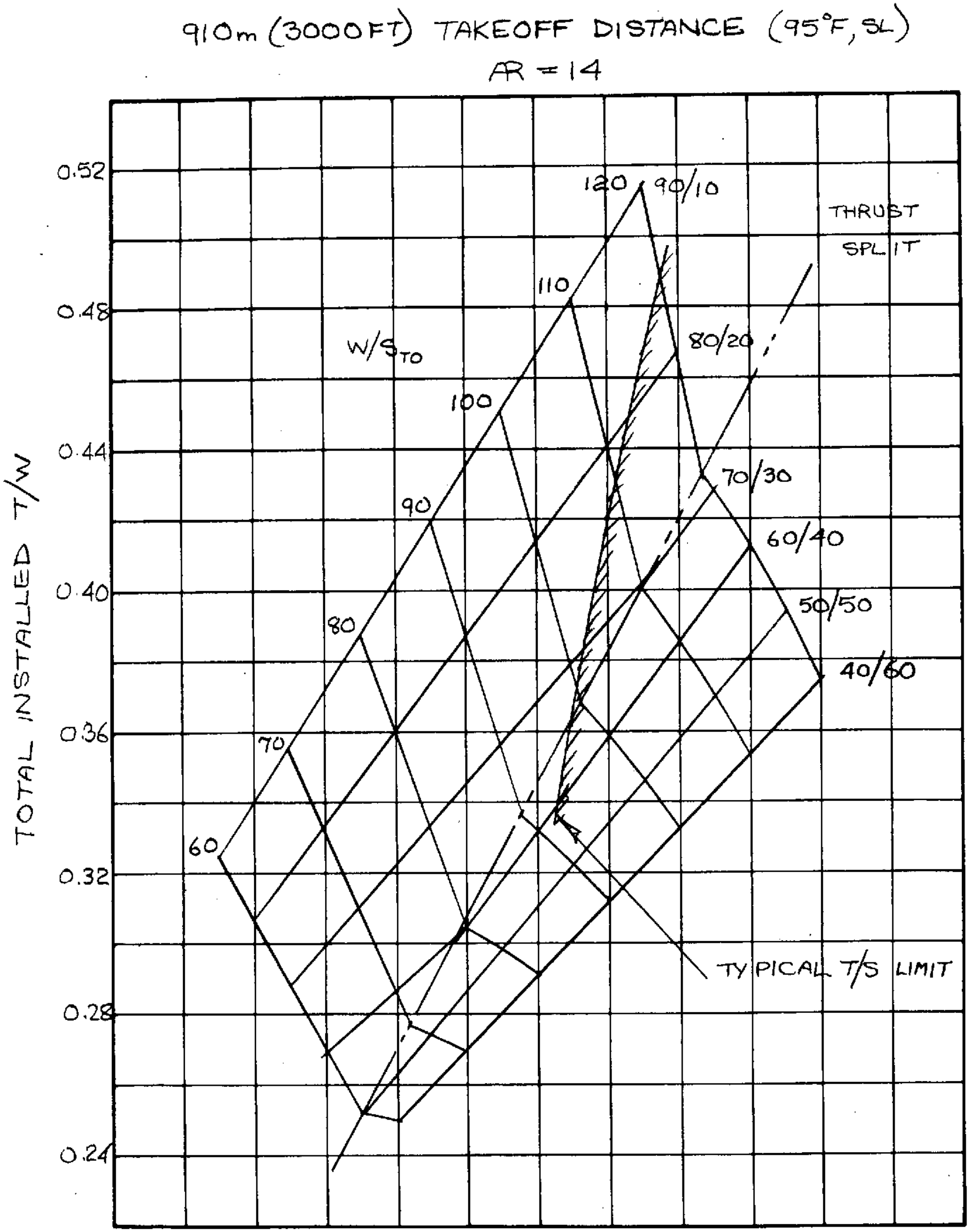


FIGURE 191: LOAD COMPRESSOR AW: T/W VS W/S AND THRUST SPLIT (AR = 14)

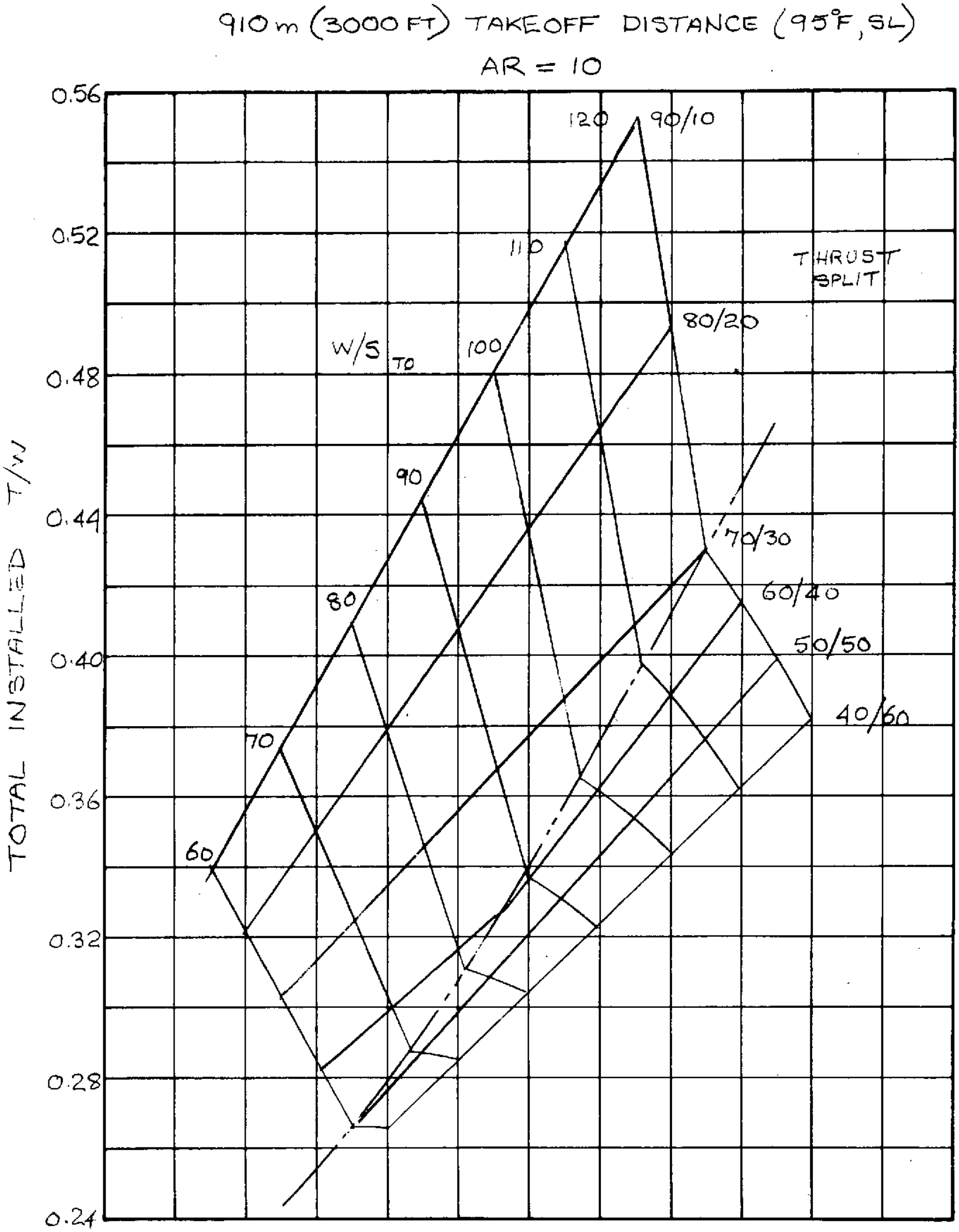
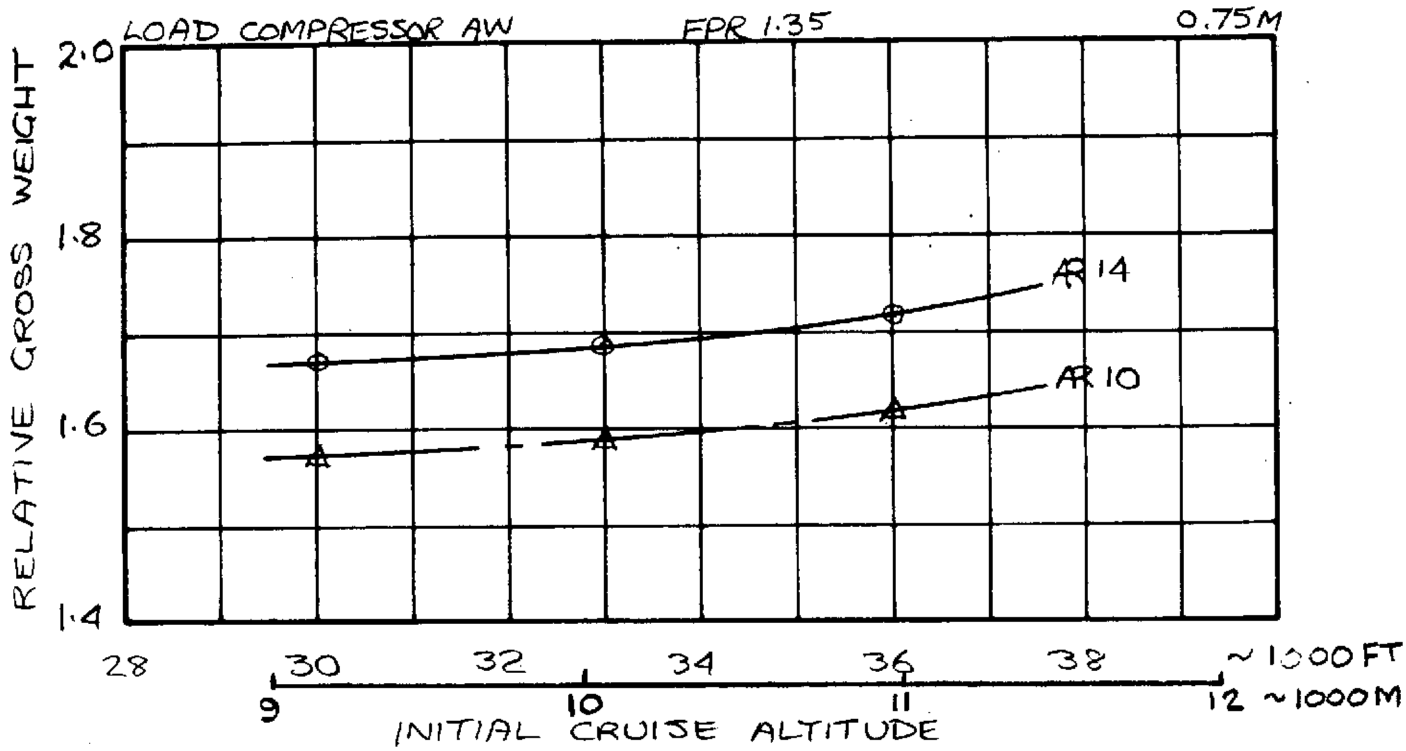


FIGURE 192: LOAD COMPRESSOR AW: T/W VS W/S AND THRUST SPLIT (AR = 10)



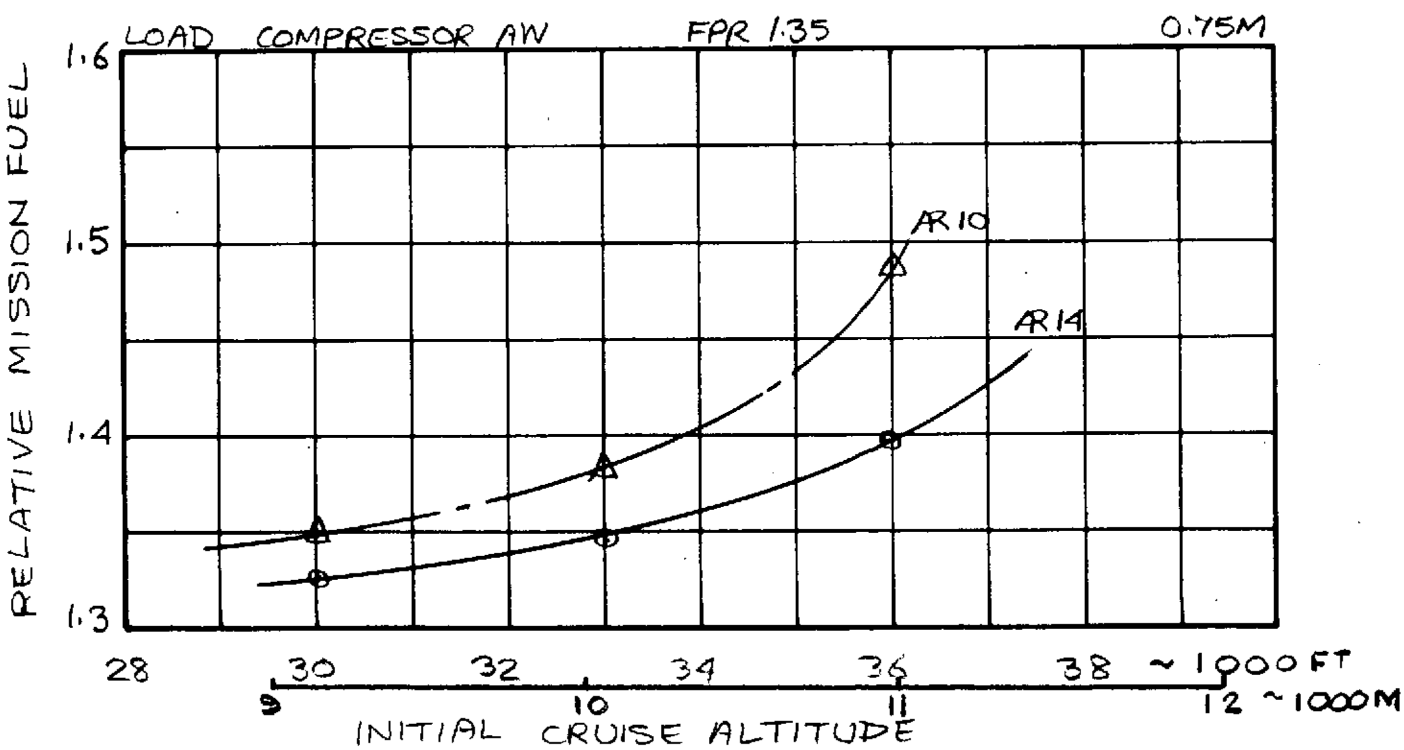
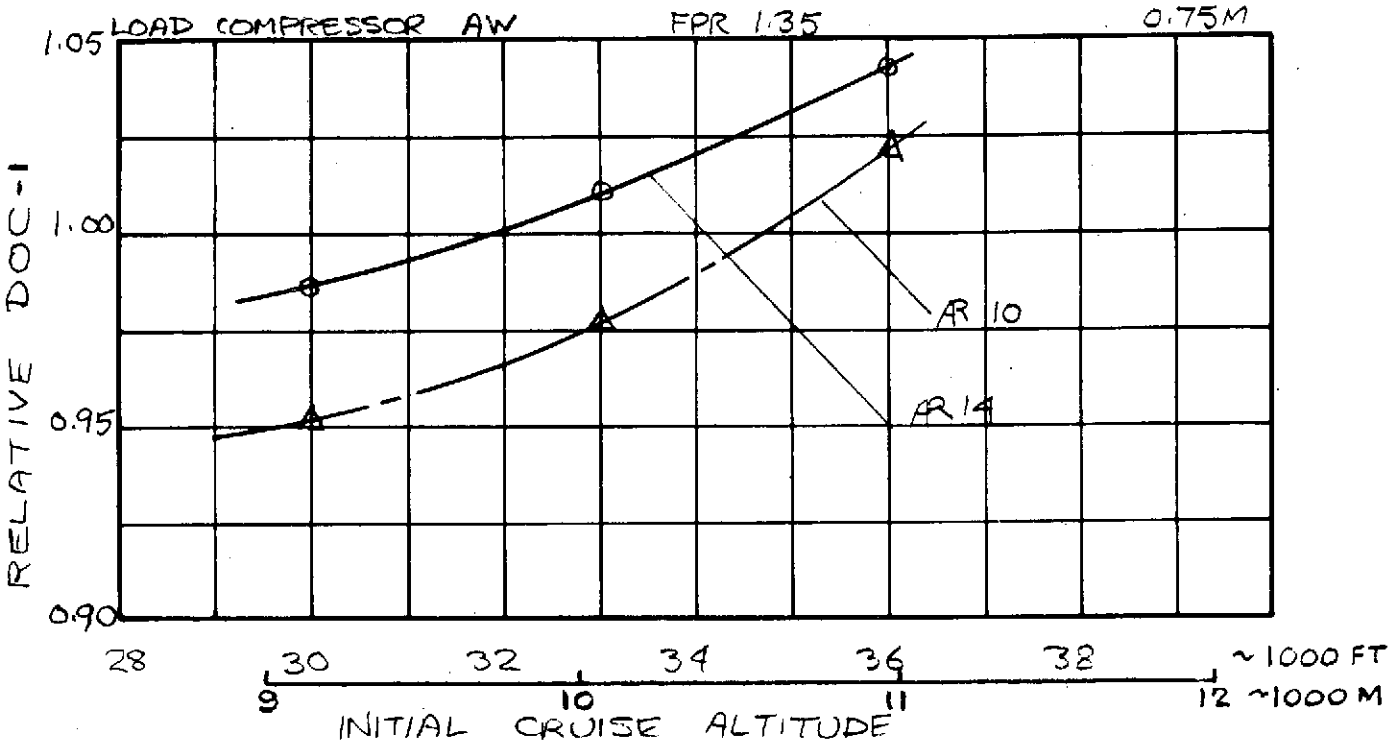


FIGURE 193: LOAD COMPRESSOR AW: GROSS WEIGHT AND MISSION FUEL VS CRUISE ALTITUDE



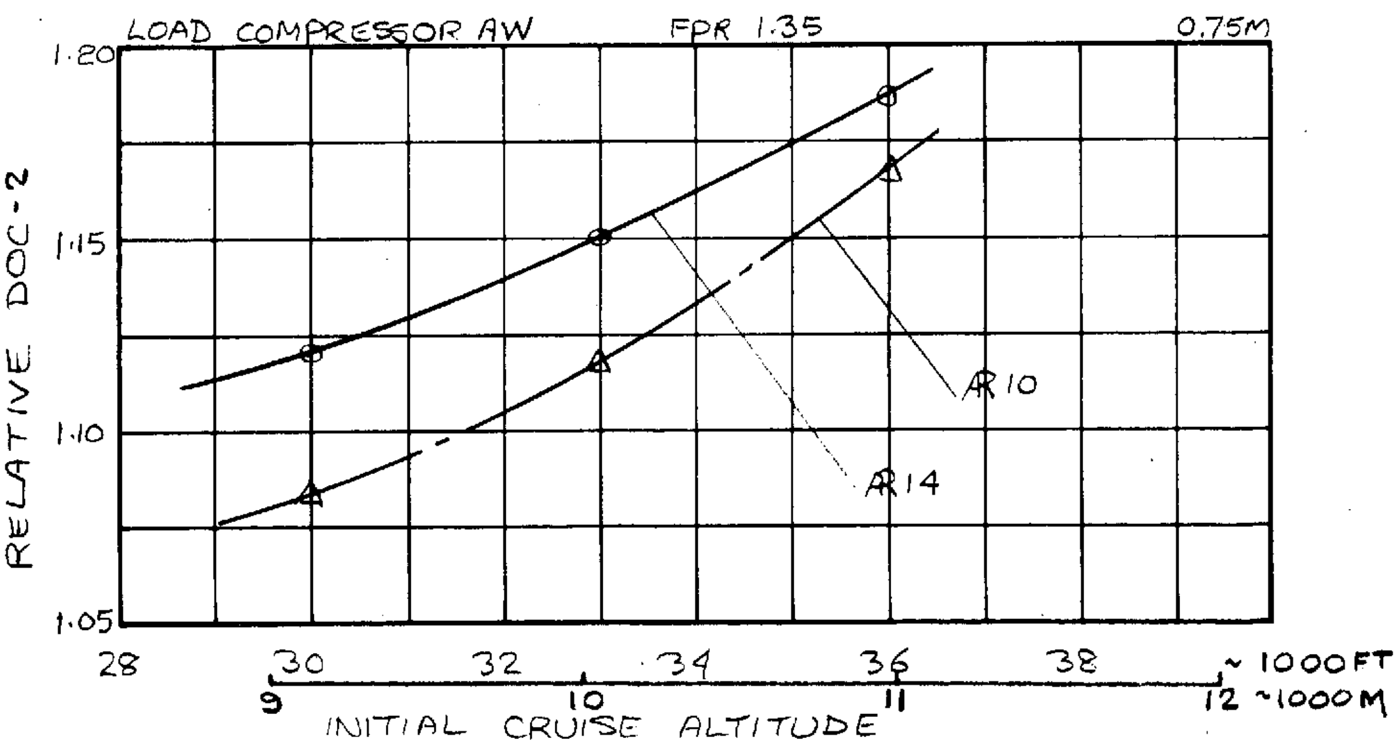
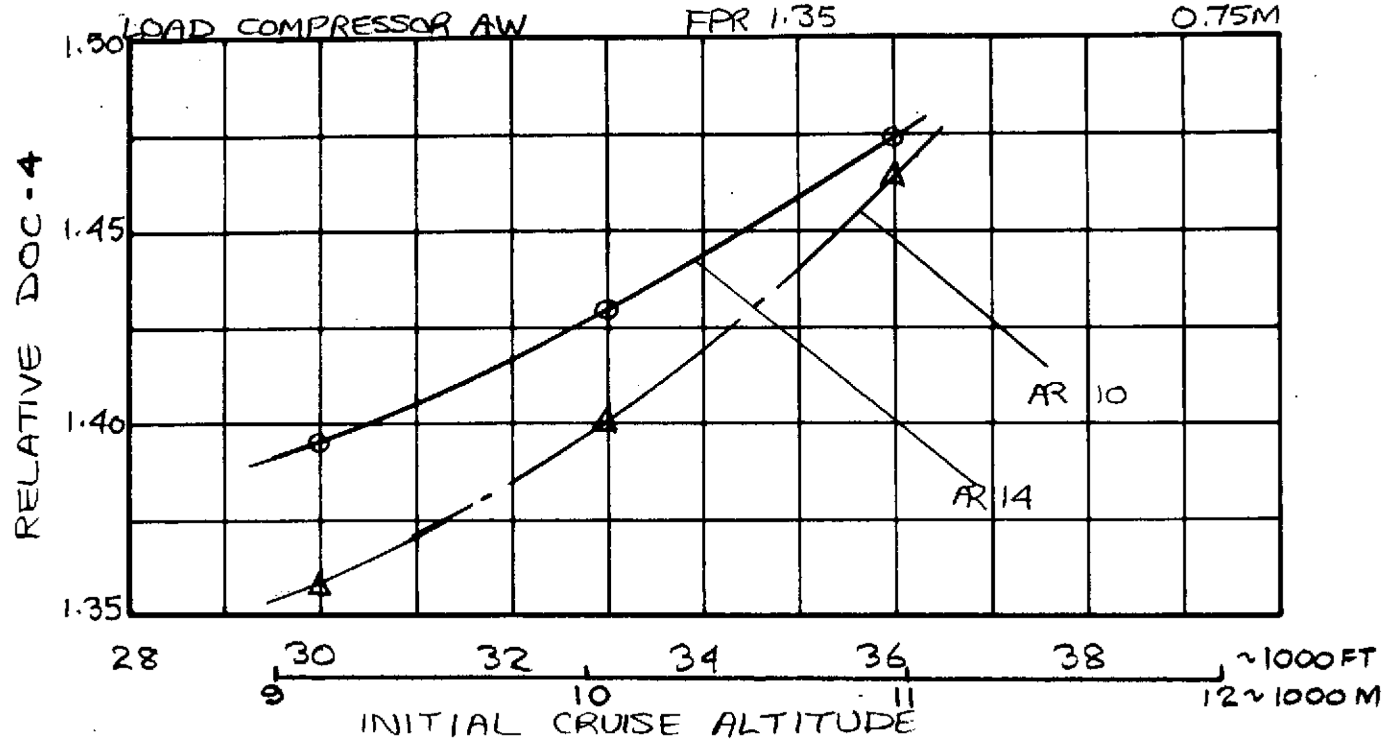


FIGURE 194: LOAD COMPRESSOR AW: DOC-1 AND DOC-2 VS CRUISE ALTITUDE



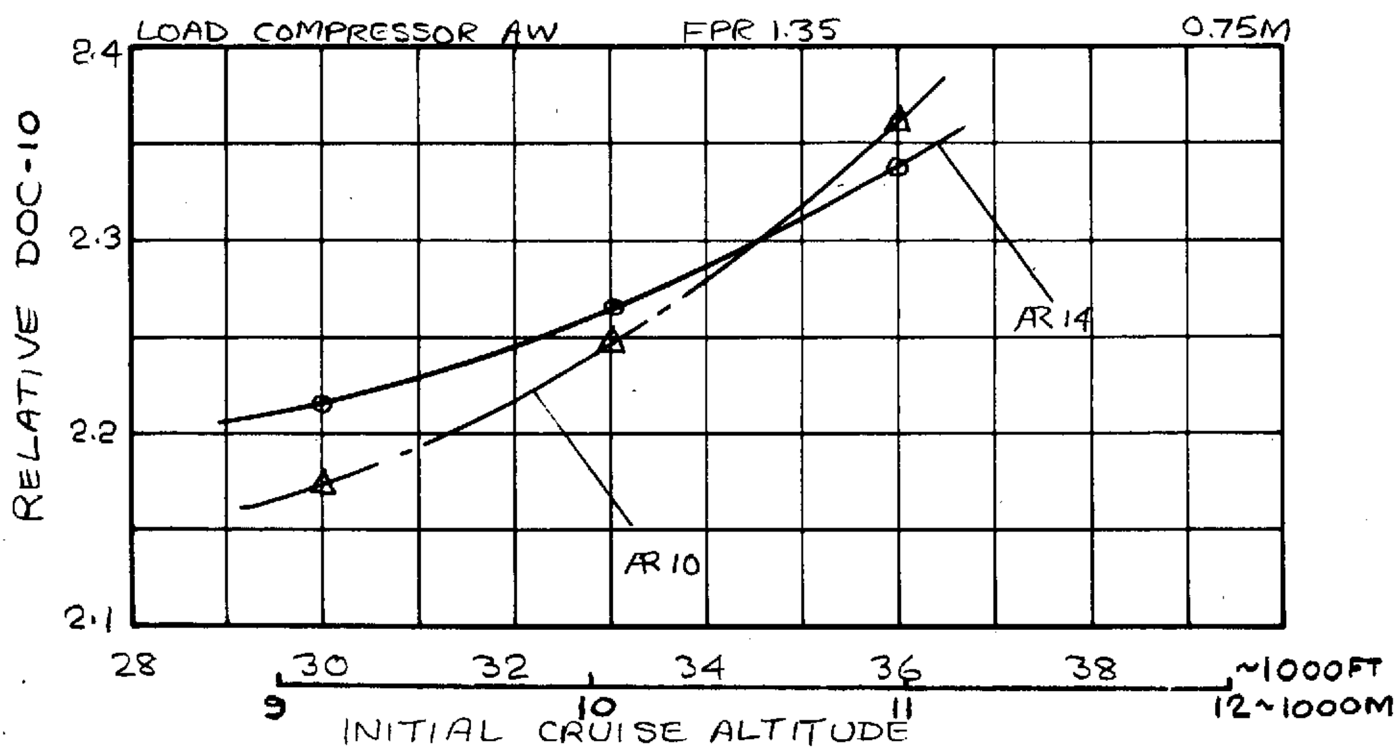


FIGURE 195: LOAD COMPRESSOR AW: DOC-4 AND DOC-10 VS CRUISE ALTITUDE

for minimum fuel is slightly under 9140m. (30,000 ft.) but that the minimum-cost cruise altitude is substantially less than 9140m. (30,000 ft.) and probably in the region of 7620m. (25,000 ft.) although no data have been developed for this altitude. Whereas the aspect ratio 14.0 configurations yield the least fuel consumption, the lower aspect ratio considered (10.0) yields the least costs. These results are in general conformity with the optimum aspect ratios determined in the more comprehensive studies which have been made of the hybrid OTW-IBF, as is to be expected from the similarities of the two concepts.

The optimum thrust split (71.5% cruise thrust: 28.5% load compressor thrust) and optimum wing loading (103 lb/sq. ft.) derived from the matching of cruise and takeoff requirements lie in the region of critical cruise-engine failure above the chain-dotted line in Figure 191; the region below this line denotes the failure of a load-compressor to be takeoff critical. Hence, the use of 3 or 4 load compressors in lieu of the 2 assumed initially (which would make load-compressor failure even less critical) would alter neither the total installed thrust nor the optimum thrust split. Thus, there would be no change in the mission fuel but, because of the additional acquisition and maintenance cost of the multiple load-compressors, the direct operating cost would be adversely affected. In this context it should be noted that no other applications for the FPR 3.0 load compressor are foreseen and it is accordingly assumed that RDT&E and manufacturing costs must be defrayed over a fixed number of aircraft sets regardless of the number of units per set. Thus, the additional production cost of the larger number manufactured raises the acquisition cost per pound of installed thrust per airplane.

The foregoing is predicated upon a similar wing-root location for the installation of the load-compressors and no change in the T/S limitations. Were the multiple load-compressors to be relocated at their optimum spanwise locations from the duct standpoint, despite the impracticality of a centerline mounting for a third load compressor, the T/S limit could be raised at some increase in installation cost, weight and drag arising from the discrete individual nacelles. This would shift the maximum wing loading boundary in Figure 191 to the right and would define a new optimum configuration with higher wing loading and a revision of the optimum thrust split to increase the proportional load-compressor thrust. Conservative estimates of these changes are presented in Table XIX (in that the additional installation penalties noted above are not recognized). Because of the additional number of load-compressors, cruise engine failure remains the critical factor in defining the takeoff thrust required despite the amended thrust splits indicated in the table. Thus, the total installed thrust/weight ratio is increased with multiple load-compressors and at the higher wing loadings implied, the total load-compressor thrust increases significantly but the cruise thrust only diminishes very slightly. The improvement in cruise fuel consumption is almost exactly counterbalanced by the increased load compressor fuel (for 10 minutes operation) and only trivial changes in overall mission fuel are indicated. However, the increase in load compressor acquisition and maintenance costs are reflected in an increased overall DOC and the multiple load compressors are therefore shown to be inferior to the selected dual installation.

Leading characteristics of the selected load-compressor vehicles for alternately minimum DOC-2 and minimum mission fuel are presented in Table XX. Figure 196 presents the 3-view of the latter vehicle which apart from its higher aspect raio is also generally representative of the former configuration. A comparison of the optimum load-compressor AW vehicles for minimum fuel and minimum DOC-2 with their OTW-IBF and orthodox AW counterparts is presented in Figures 197 and 198 which demonstrates the substantial benefit which the load compressor affords the AW vehicle. However, the improved capability has been shown to remain non-competitive with respect to the OTW-IBF powered lift concept.

TABLE XIX: COMPARISON OF 2, 3, AND 4 LOAD-COMPRESSOR ARRANGEMENTS

(148 PASS. @ 926 Km (500 N.M.) RANGE @ 910m (3000 FT) FIELD;

0.75M @ 9140m (30,000 FT))

No. of Load Compressors		2	3	4
No. Cruise Engines		2	2	2
Cruise Engine FPR		1.35	1.35	1.35
Wing Loading	Kg/m^2	503	547	586
	(lb/sq ft)	103	112	120
Takeoff Thrust/Weight	N/Kg	3.85	3.93	4.04
(Cruise Engs. + Load Comp.)	(lb/lb)	0.392	0.401	0.412
Thrust Split (Cruise Eng./Load Comp.)		0.715/0.285	0.695/0.305	0.675/0.325
Ramp Cross Weight	Kg	69,073	68,193	67,313
	(lb)	152,280	150,340	148,400
Uninstalled Cruise Eng. Thrust	KN	103.6	101.4	100.1
(Per Engine)	(lb)	23,280	22,800	22,500
Uninstalled Load Comp. Thrust	KN	41.6	30.0	24.2
(Per Engine)	(lb)	9,350	6,740	5,450
Mission Fuel	Kg	5,583	5,535	5,602
	(lb)	12,309	12,202	12,350
DOC-2	¢/ASSM	2.079	2.104	2.147

TABLE XX: PRINCIPAL CHARACTERISTICS OF LOAD-COMPRESSOR AW

(148 PASS. @ 926Km (500 N.M.) RANGE @ 910m (3000 FT.) FIELD)

Optimization Basis		Min. DOC-2	Min. Fuel
FPR (Cruise Engines)		1.35	1.35
FPR (Load-Compressor)		3.0	3.0
No. Cruise Engines		2	2
No. Load-Compressors		2	2
Cruise Mach No.		0.75	0.75
Initial Cruise Altitude	m	9,140	9,140
	(ft.)	30,000	30,000
Aspect Ratio @ Sweep (Degrees)		10.0 @ 10°	14.0 @ 10°
Takeoff Wing Loading	kg/m^2	547	503
	(lb/sq ft)	112.0	103.0
Takeoff Thrust/Weight	N/Kg	4.05	3.85
(Cruise Engs. + Load Comp.)	(lb/lb)	0.413	0.392
Uninstalled Thrust	KN	103.1	103.6
(Cruise Eng. only)	(lb)	23,188	23,282
Wing Area	m^2	118.9	136.8
	(sq ft)	1,280	1,473
Ramp Gross Weight	Kg	65,032	69,074
	(lb)	143,370	152,281
Operating Weight Empty	Kg	44,809	49,033
	(lb)	98,786	108,099
Mission Fuel	Kg	5,688	5,583
	(lb)	12,539	12,309
DOC (1)	¢/ASSM	1.760	1.825
(2)	¢/ASSM	2.015	2.079
(4)	¢/ASSM	2.517	2.587
(10)	¢/ASSM	4.036	4.111

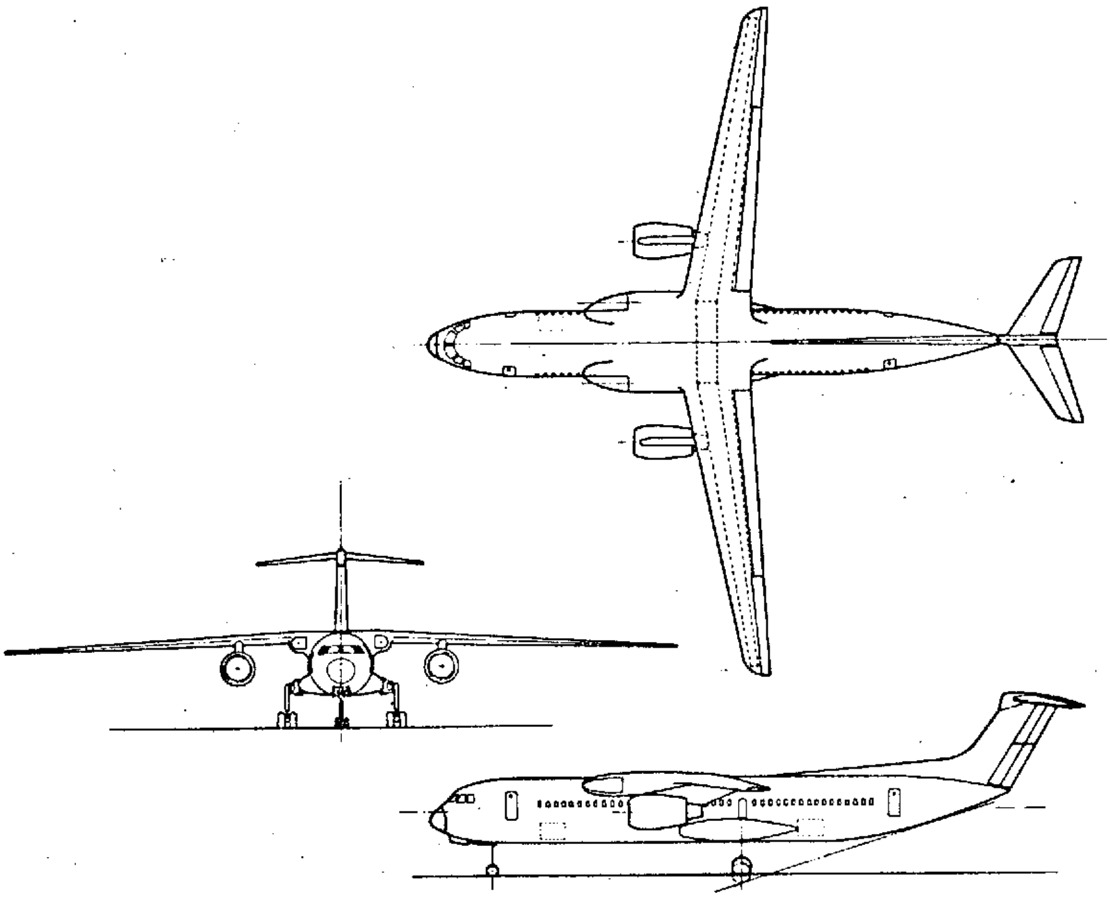


FIGURE 196: LOAD COMPRESSOR AW: GENERAL ARRANGEMENT

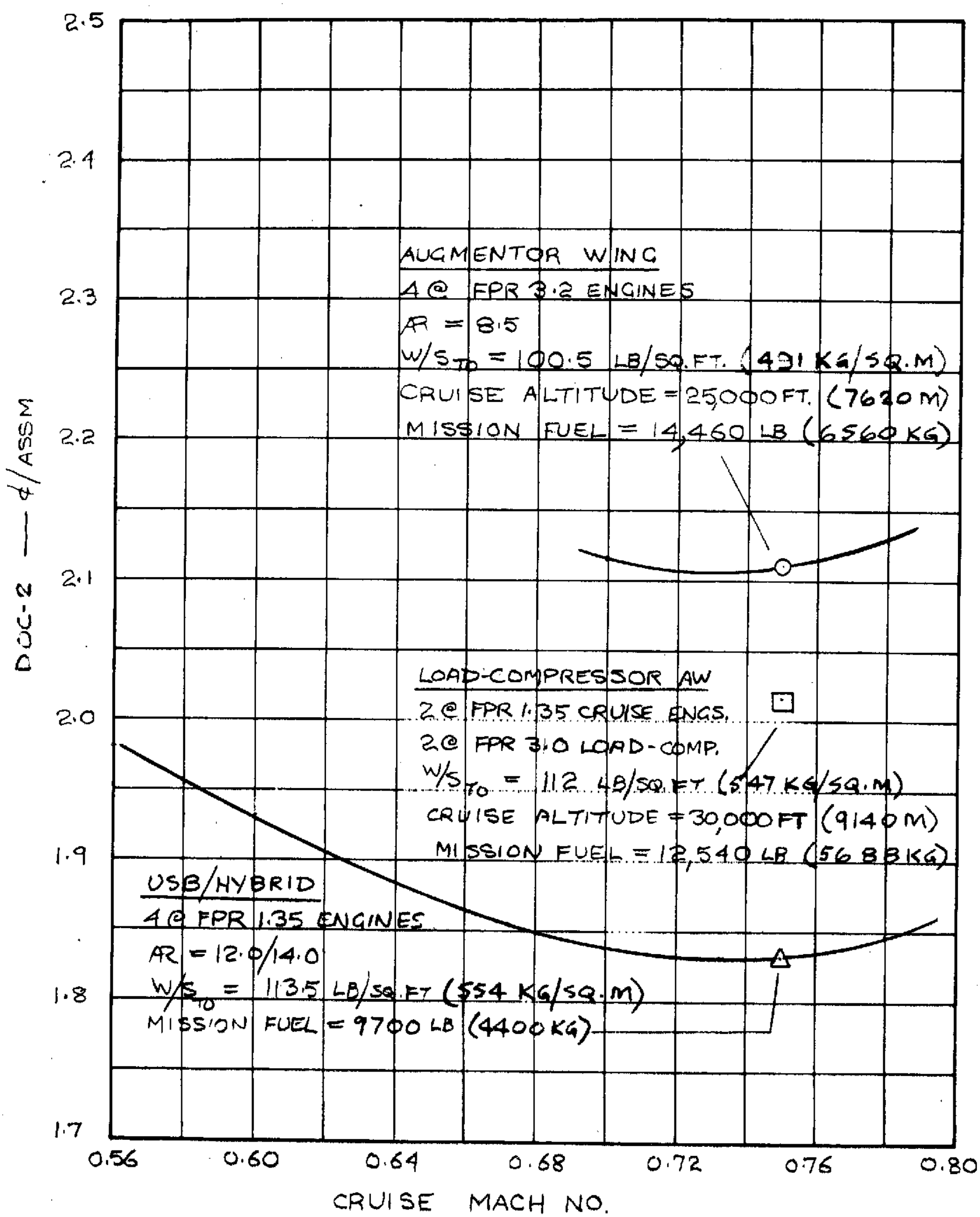


FIGURE 197: DOC COMPARISON: AUGMENTOR WING VS OTW/IBF

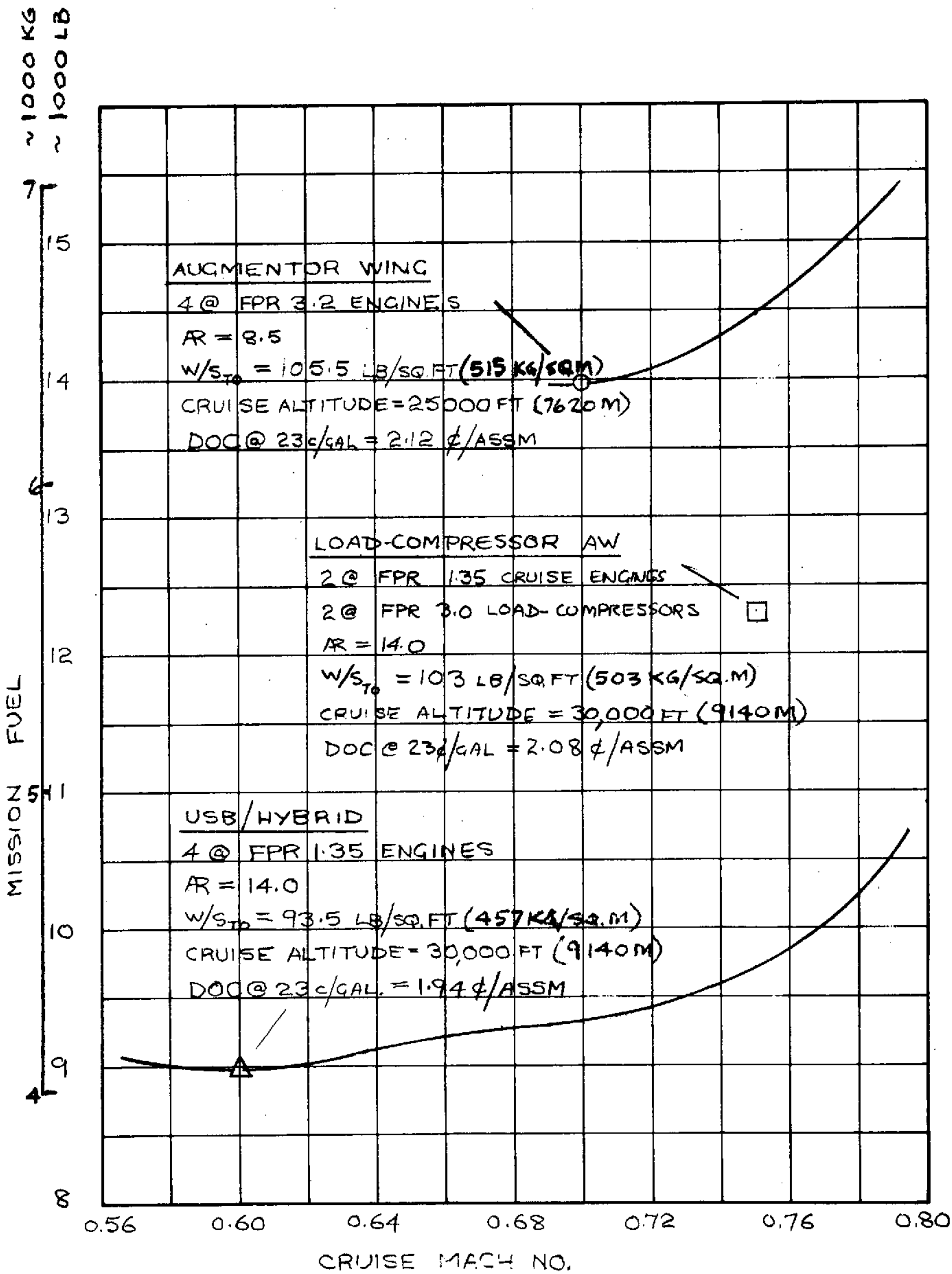


FIGURE 198: MISSION FUEL COMPARISON: AUGMENTOR WING VS OTW/IBF

5.6 NOISE ANALYSES

The methods described in Section 4.9 and in Reference 2 were applied to the augmentor wing aircraft having engines with 3.0 FPR. As noted in Section 2.8.2.3 of Reference 2 a fan inlet attenuation of approximately 30 dB is required and References 31 and 32 indicate this can be achieved. Exhaust noise attenuation by the augmentor flap was based on the data of References 32 and 33.

5.6.1 Noise Results

A summary of the aircraft characteristics and of the noise footprint characteristics is given in Table XXI. The noise data were obtained from analysis of the FPR 3.0 aircraft but are expected to be closely representative of the improved aircraft with FPR 3.2 engines. Further comparison and discussion of the results is given in Section 8. Noise contours are plotted in Figure 199.

TABLE XXI : AUGMENTOR WING NOISE ANALYSIS 910 m. (3000 FT.) FIELD LENGTH

4 ENGINES FPR 3.0 FIXED PITCH DIRECT DRIVE TIP SPEED 1577 fps

SINGLE ENGINE THRUST 64.9 KN (14,586 LB) GROSS WEIGHT 68,897 Kg (154,097 LB)

T.O. FLAP SETTING 14 DEGREES CLIMB VELOCITY 224 Km/HR (121 KTS)

SIDELINE NOISE: EPNdB @ DIST:

95 @ 152 m. (500 FT.)
88 @ 305 m. (1000 FT.)
80 @ 648 m. (0.35 N.M.)

APPROACH NOISE: EPNdB @ DIST:

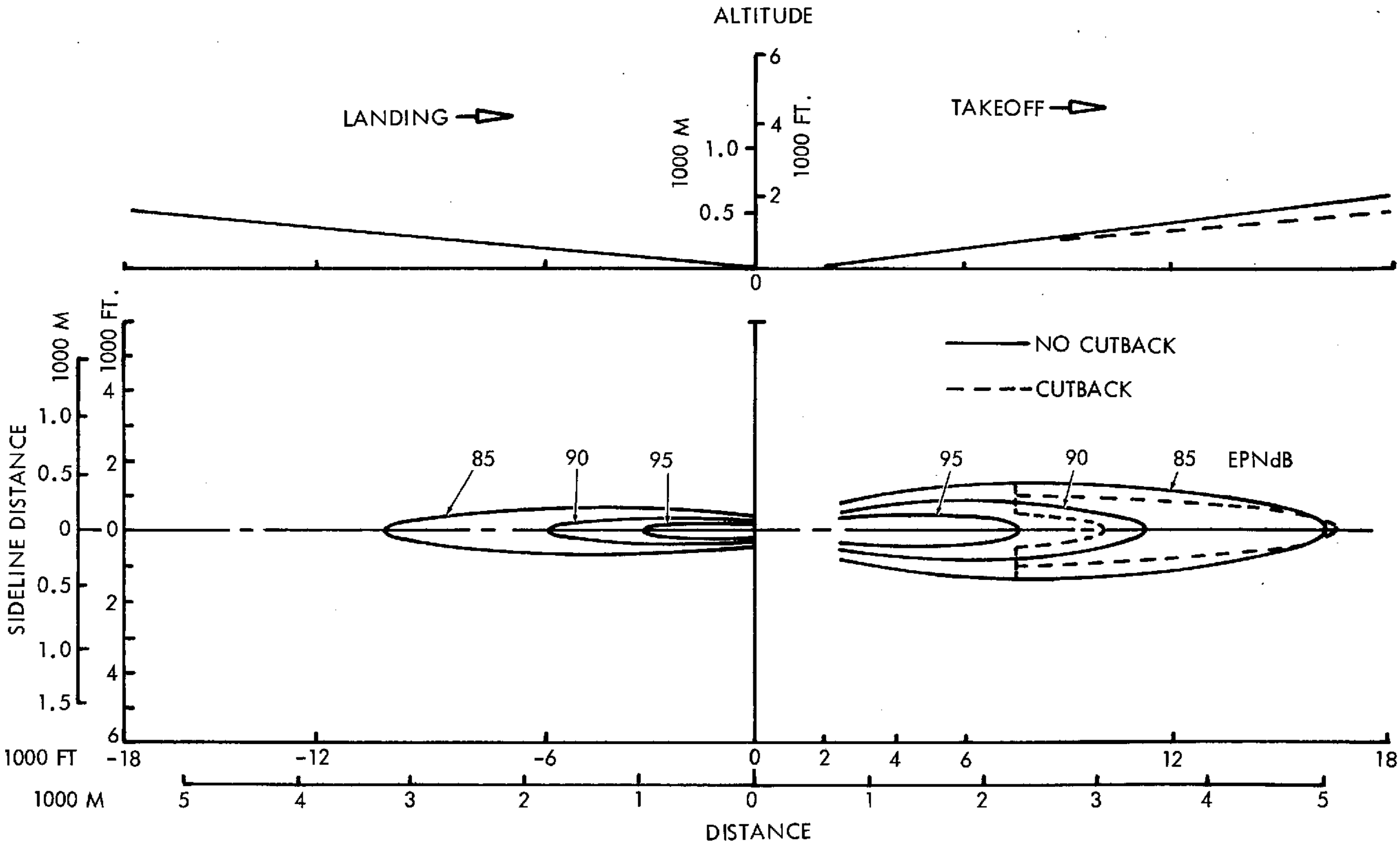
90 @ 1850 m. (1 N.MI.)

TAKEOFF FLYOVER NOISE: EPNdB @ DIST:

95 @ 2290 m. (7500 FT.)
90 @ 3050 m. (10,000 FT.)
85 @ 5180 m. (17,000 FT.)
82 @ 7920 m. (26,000 FT.)

FOOTPRINTS:

CONTOUR	APPROACH				TAKEOFF AREA		TOTAL AREA	
	LENGTH		AREA					
	m.	FT.	SQ. Km	SQ. MI.	SQ. Km	SQ. MI.	SQ. Km	SQ. MI.
95 EPNdB	910	3000	0.39	0.15	0.52	0.2	0.91	0.35
90 EPNdB	1830	6000	0.65	0.25	0.78	0.3	1.42	0.55
85 EPNdB	3200	10500	1.04	0.4	2.72	1.05	3.76	1.45
80 EPNdB	5180	17000	2.85	1.1	5.96	2.3	8.81	3.4



FPR = 3.0

FIGURE 199: NOISE FOOTPRINT CONTOURS (EPNdB)

6.0 MECHANICAL FLAP (MF) VEHICLES

6.1 MF CONCEPT

The design studies accomplished in Reference 2 included propulsive lift systems for field lengths of 910m. (3000 ft.) or less and mechanical flap vehicles at 1220m. (4000 ft.) with a parametric excursion to 910m. (3000 ft.). All of these vehicles had a common 95 EPNdB sideline noise level and extensive acoustic treatment. A more economical means of noise compliance is a fan pressure ratio reduction and a wall-treated nacelle. Whereas Reference 2 suggested that the "critical field length" at which the economic advantages passes from the MF to a powered lift system lay approximately half way between 1220m. (4000 ft.) and 910m. (3000 ft.), a more refined comparison at a common field length was indicated to be desirable. This section of the report presents the conceptual MF design studies subsequently accomplished to improve the credibility of economic and noise level comparisons with the hybrid OTW-IBF and AW vehicles. Both advanced CTOL engines with fan pressure ratios of around 1.5 and lower fan pressure ratio engines with exclusively STOL applications have been considered. Inasmuch as the common use of only wall treated nacelles for all pressure ratios precludes the achievement of a common noise level (in general), these engine selections also imply the consideration of two different noise standards.

As for the OTW/IBF hybrid concept, MF configurations have been optimized for DOC at 1972 fuel prices, for minimum fuel consumption at varying field length, and for fuel costs of 2, 4 and 10 times the 1972 price level. Subsequent subsections describe the data base, configuration sizing and optimization analyses conducted for each of these conditions. Those configurations which principally address the baseline mission derived in Ref. 2 and a field length of 910m. (3000 ft.) are described in Section 6.4 and have been optimized on the basis of minimum operating cost at 1972 fuel prices. These are predicated upon the use of a fuselage seating 6 abreast in a single aisle arrangement and have high wing, tee-tail configurations with fuselage mounted landing gear and large, underwing, pylon-mounted nacelles. The high lift system comprises a double-slotted flap of 35% chord and a 17% chord leading edge flap; it having been shown in Rev. 2 that the advantages of the double slotted concept with respect to go-around and takeoff climb gradient outweigh conceivable $C_{L\ MAX}$ advantages of the triple slotted flap despite the landing criticality of the MF vehicle.

As has been indicated already in Section 4.1, there are wetted surface area and weight advantages to a fuselage with 5 abreast seating (for 148 passengers) which has been adopted for all fuel-conservative configurations addressed in Section 6.5. These vehicles are characterized by higher aspect ratios than the baseline mission vehicles and, with a four engine arrangement, permit a low wing arrangement with wing mounted gear to be used to accommodate the longer fuselage and greater tail-down clearance angle. This configuration is also appropriate to the longer field length two-engine vehicles but the larger engine sizes at the short field lengths may dictate a high wing location and the original fuselage size to avoid gear stowage problems. In all other respects, the fuel conservative configurations conform to the baseline concept.

6.2 MF PROPULSION DATA

To meet the requirements for fan pressure ratio variations required by the present study effort, engines have been selected from Phase I and Phase II of the NASA-Lewis Contract NAS2-16727 QCSEE Study. These engines provided the most consistent data available for the pressure ratios and technology levels (mid 1980's) desired for the study. Additional sets of engine data have been derived for higher fan pressure ratios, representative of the RB211, CF6 and JT9D, with modification factors for technology advances to achieve consistency with the engines of Ref. 2. A 1.47 FPR turbofan, which is under active development, has also been introduced into the study. This is an advanced-technology, low-noise engine in the 22,000 lb. S.L.S.T. class, and is expected to be certified in late 1977. Rubberized parametric data have been generated based on this engine as being representative of an intermediate by-pass engine suitable for an advanced CTOL.

The uninstalled engine performance data were generated by UNIVAC 1106 cycle matching computer programs. Dimensions, weights, and costs were scaled using the Reference 2 factors. The power extraction and climb and cruise environmental control system airbleed losses for which allowance has been made are 140 horsepower total and 220 lb./min. mid-stage airbleed total for a 148 passenger aircraft. It has been concluded that the most economic nacelle/acoustic treatment combination comprises a nacelle which is designed by propulsive and aerodynamic consierations only and has only that quantity of wall treatment which does not impair the internal and external flow characteristics. The installation losses of such a combination have been included in the comparison of installed engine characteristics presented in Table XXII. It should be noted that installed engine data from Reference 2 have been used directly for baseline number-of-engines optimization studies. These data therefore assume a level of acoustic treatment which is excessive for optimum economic operation but do not invalidate a two, three, and four engine configurational comparison. Specific mission vehicles with the selected number of engines are correctly predicated upon wall-treated nacelles.

FAN PRESSURE RATIO	1.35	1.40	1.50	1.574	1.47
FAN TYPE	F/P	F/P	F/P	F/P	F/P
UNINSTALLED T/W (T.O.)*	6.84	6.77	6.40	6.10	5.68
INSTALLED T/W (T.O.)**	4.10	4.10	4.10	4.25	3.72
INST. SPEED LAPSE RATE (0.2 M)	0.762	0.771	0.791	0.813	0.792
UNINSTALLED $/T (T.O.)*	28.30	28.30	28.30	28.30	25.70
INSTALLED $/T (T.O.)**	40.50	40.20	39.20	37.40	36.70
INST. ALTITUDE LAPSE 0.8M/9140M (30,000 FT)	0.183	0.190	0.207	0.225	0.227
INST. CRUISE SFC LB/LB/HR	0.722	0.731	0.749	0.758	0.792
0.8M/9140M (30,000 FT) KG/N/HR	0.0740	0.0749	0.0768	0.0777	0.0811

* RATED THRUST SCALED TO 133 KN (30,000 LB)

** S.L., 95°F @ SCALED RATED THRUST

TABLE XXII: MF CANDIDATE ENGINE CHARACTERISTICS
(PROPULSION-AERODYNAMIC DESIGNED NACELLE, WALL TREATMENT ONLY)

The nacelle configurations for two of the candidate MF engines are shown in Figure 200. These nacelles represent aerodynamic designed internal and external contours with no compromise for acoustic materials. However, acoustic materials are installed on walls of the inlet and exhaust ducts where this treatment does not interfere with the internal aerodynamic lines. The aft nacelle contains a set of cascade vanes and blocker doors to reverse the fan exhaust stream for thrust reverse operations; the primary stream will remain unaltered. The nacelle inlet/forebody shapes have been designed by proven Lockheed methods and charts to provide good cruise recovery levels while maintaining reasonable losses for terminal area operations. The pressure recovery losses are of the order of 1.5% for lift-off speeds and 0.5% for cruise. Exhaust duct pressure losses are approximately 1% for the fan exhaust and 0.3% for the primary duct with velocity coefficients of 0.995 for both streams. Nacelle external drags have been computed and have been included in the installed engine data. Major nacelle dimensions of all engines for the MF airplanes are presented in Figure 201.

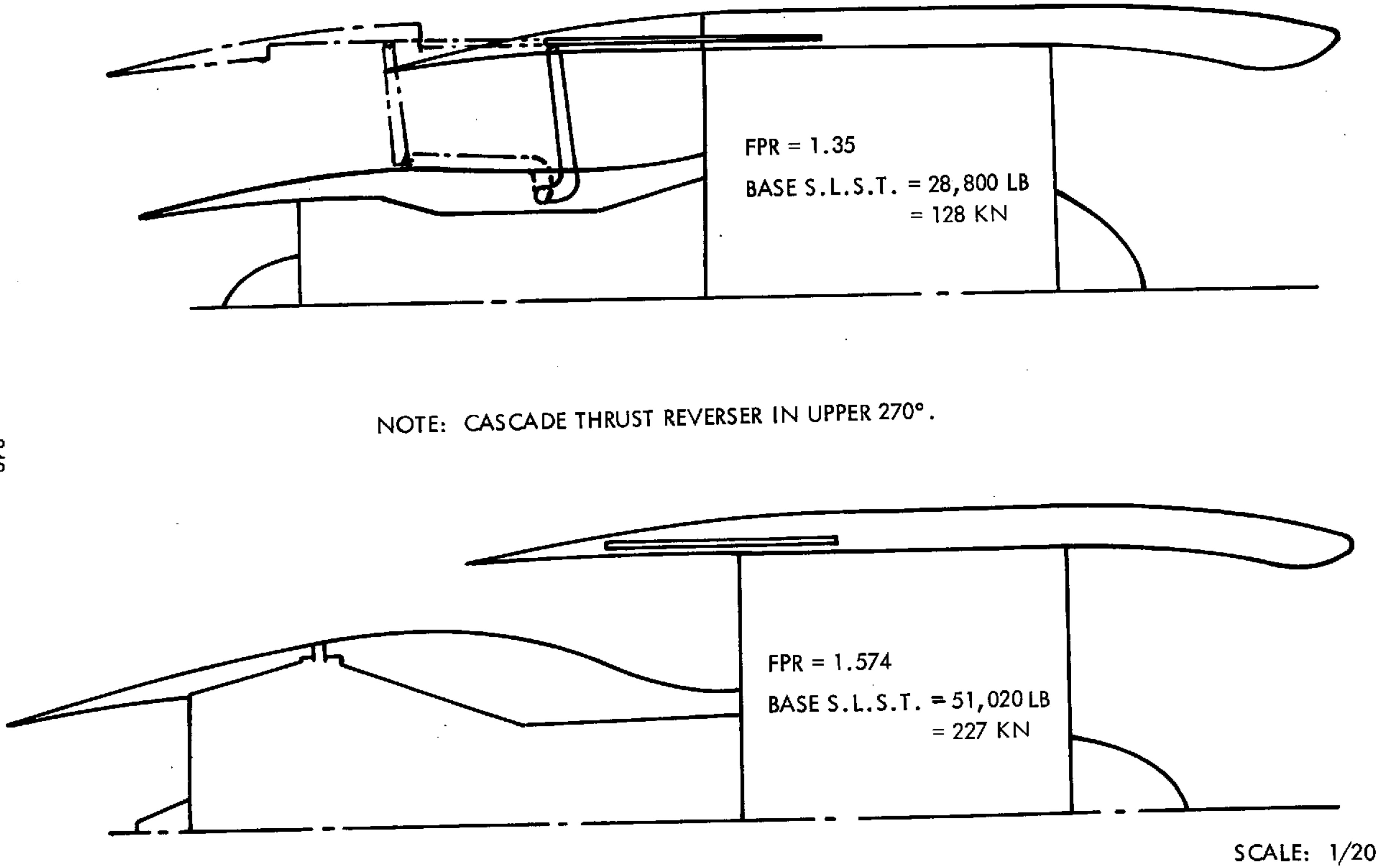
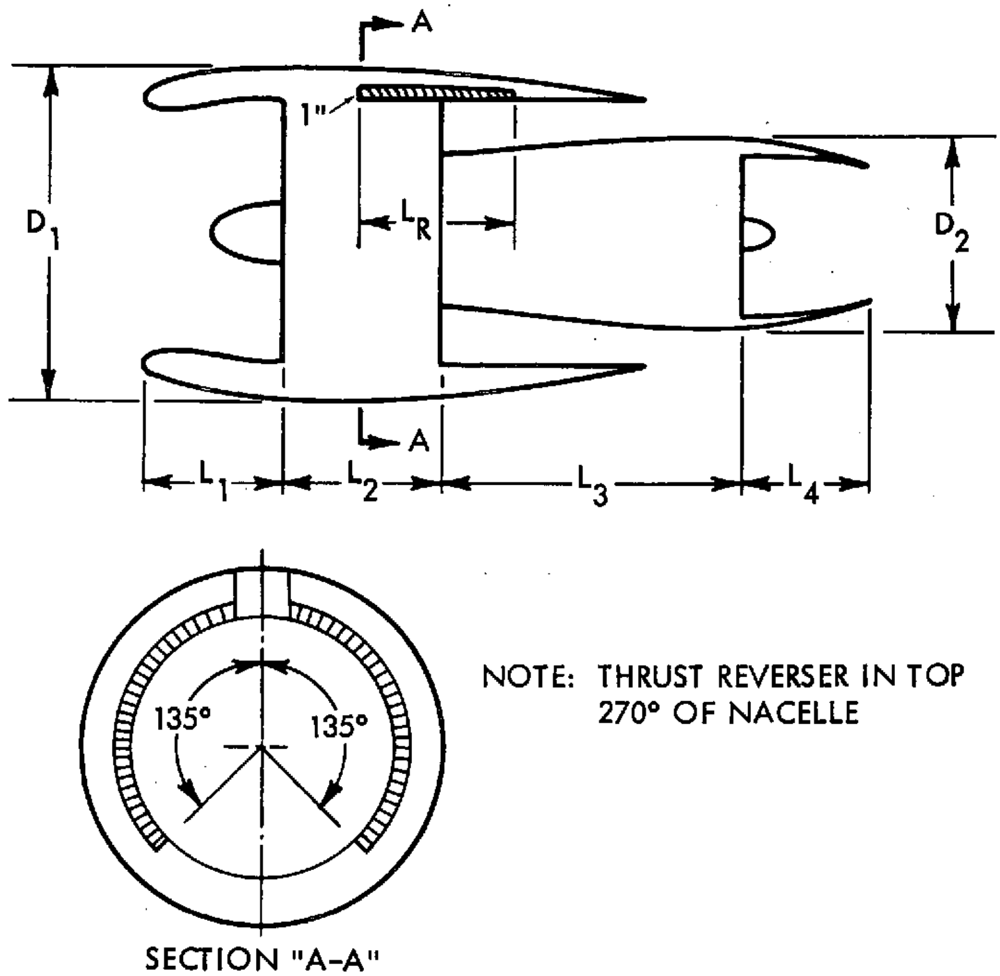


FIGURE 200: MECHANICAL FLAP NACELLES



NOTE: THRUST REVERSER IN TOP 270° OF NACELLE

FAN PRESSURE RATIO	1.35	1.40	1.50	1.574
D_1 - IN.	97.8	80.3	78.3	105.8
D_2 - IN.	46.0	43.1	41.8	66.0
L_1 - IN.	49.0	39.4	37.6	50.0
L_2 - IN.	116.0	89.7	79.5	105.0
L_3 - IN.	16.0	17.7	26.5	48.0
L_4 - IN.	29.0	23.1	22.1	31.0
L_R - IN.	31.8	20.0	16.5	26.6
RATED THRUST - LB.	28,800	20,000	20,000	51,020

FIGURE 201: ESTIMATED MECHANICAL FLAP NACELLE DIMENSIONS

6.3 MF AERODYNAMIC DATA

The MF vehicles retain the double slotted flap adopted in previous phases of this study which are reported in Reference 2. Hence, no changes have been made to either the low speed or the high speed data base previously used. A more complete printout of the low speed data than that contained in Reference 2 is presented in Table XXIII. In addition, a summary of typical takeoff and landing flap settings for baseline MF vehicles is presented in Table XXIV. The flap angle selections noted are a result not only of field length requirements but also of constraints imposed by the Federal Aviation regulations with respect to other requirements such as second segment and go-around climb gradients. Lift and drag characteristics for the MF design are compared with other data sources in terms of L/D at 1.2 V_S versus $C_{L\ MAX}$ in Figure 202. A comparison of $C_{L\ MAX}$ versus flap setting is given in Figure 203. The effect of $C_{L\ MAX}$ on landing field length and approach speed is illustrated in Figures 204 and 205. These comparisons validate the MF data base.

For all aircraft optimization studies in this phase, the effects of geometrical changes to aspect ratio, sweep and taper ratio have been represented by:

- o Correcting induced drag (or C_X force) for aspect ratio.
- o Assuming no sweep penalty on $C_{L\ MAX}$.
- o Assuming taper ratio effects can be compensated for by optimization of wing twist and high lift devices.

This is consistent with the methodology used in deriving the corresponding effects for powered lift concepts described in Section 4.3 which also describes the drag estimation methodology for all vehicles. This approach permits the more significant effects of geometric variations to be included in the critical optimization while giving a slight advantage to the higher sweep angles and taper ratios. Results of the optimization studies verify that the above parametric simplifications do not significantly affect the selection of aspect ratio, sweep and taper.

AR = 7

δ_F	.00000	.00000					
C_T	.00000	1.00000	2.00000	4.00000			
α	-4.00000	4.00000	12.00000	16.00000	20.00000	24.00000	28.00000
C_L	.00000	.56000	1.09000	1.35000	1.60000	1.83000	1.95000
	.00000	.56000	1.09000	1.35000	1.60000	1.83000	1.95000
	.00000	.56000	1.09000	1.35000	1.60000	1.83000	1.95000
	.00000	.56000	1.09000	1.35000	1.60000	1.83000	1.95000
C_X	-.03000	-.04800	-.09800	-.14000	-.18370	-.22400	-.25700
	.96756	.94956	.88016	.82128	.75602	.68958	.62599
	1.96513	1.94713	1.85831	1.78255	1.69573	1.60316	1.50898
	3.96026	3.94226	3.81462	3.70510	3.57516	3.43031	3.27496
	25.00000	.00000					
	.00000	1.00000	2.00000	4.00000			
	-4.00000	4.00000	12.00000	16.00000	20.00000	24.00000	28.00000
	.53000	1.13000	1.70000	1.96000	2.22000	2.42000	2.54000
	.53000	1.13000	1.70000	1.96000	2.22000	2.42000	2.54000
	.53000	1.13000	1.70000	1.96000	2.22000	2.42000	2.54000
	.53000	1.13000	1.70000	1.96000	2.22000	2.42000	2.54000
	-.06900	-.12400	-.22900	-.28600	-.35400	-.41300	-.45000
	.92856	.87356	.74916	.67528	.58572	.50058	.43299
	1.92613	1.87113	1.72731	1.63655	1.52543	1.41416	1.31598
	3.92126	3.86626	3.68362	3.55910	3.40486	3.24131	3.08196
	45.00000	.00000					
	.00000	1.00000	2.00000	4.00000			
	-4.00000	4.00000	12.00000	16.00000	20.00000	24.00000	28.00000
	.81000	1.42000	2.01000	2.29000	2.54000	2.76000	2.89000
	.81000	1.42000	2.01000	2.29000	2.54000	2.76000	2.89000
	.81000	1.42000	2.01000	2.29000	2.54000	2.76000	2.89000
	.81000	1.42000	2.01000	2.29000	2.54000	2.76000	2.89000
	-.14000	-.22200	-.34400	-.41500	-.48700	-.55800	-.60100
	.85756	.77556	.63416	.54628	.45272	.35558	.28199
	1.85513	1.77313	1.61231	1.50755	1.39243	1.26916	1.16498
	3.85026	3.76826	3.56862	3.43010	3.27186	3.09631	2.93096
	60.00000	.00000					
	.00000	1.00000	2.00000	4.00000			
	-4.00000	4.00000	12.00000	16.00000	20.00000	24.00000	28.00000
	.98000	1.64000	2.24000	2.53000	2.79000	3.01000	3.14000
	.98000	1.64000	2.24000	2.53000	2.79000	3.01000	3.14000
	.98000	1.64000	2.24000	2.53000	2.79000	3.01000	3.14000
	.98000	1.64000	2.24000	2.53000	2.79000	3.01000	3.14000
	-.18500	-.30100	-.45500	-.54700	-.63600	-.72500	-.77800
	.81256	.69656	.52316	.41428	.30372	.18858	.10499
	1.81013	1.69413	1.50131	1.37555	1.24343	1.10216	.98798
	3.80526	3.68926	3.45762	3.29810	3.12286	2.92931	2.75396

ACCUM TTL=1 CORE=5120 CORE SEC=181 ACCUM CPU=1

TABLE XXIII: MF BASIC AERO DATA

TABLE XXIV - TYPICAL MF TAKEOFF AND LANDING FLAP SETTINGS

ENGINE FPR	$T/W_{T/O}$	$W/S_{T/O}$	FLAP SETTINGS TAKEOFF	LANDING	APPROACH
1.35	.450	58.8	12°	66°	32°
1.4	.433	58.8	12°	66°	32°
1.5	.397	58.8	13°	66°	32°
1.574	.368	58.8	14°	66°	32°

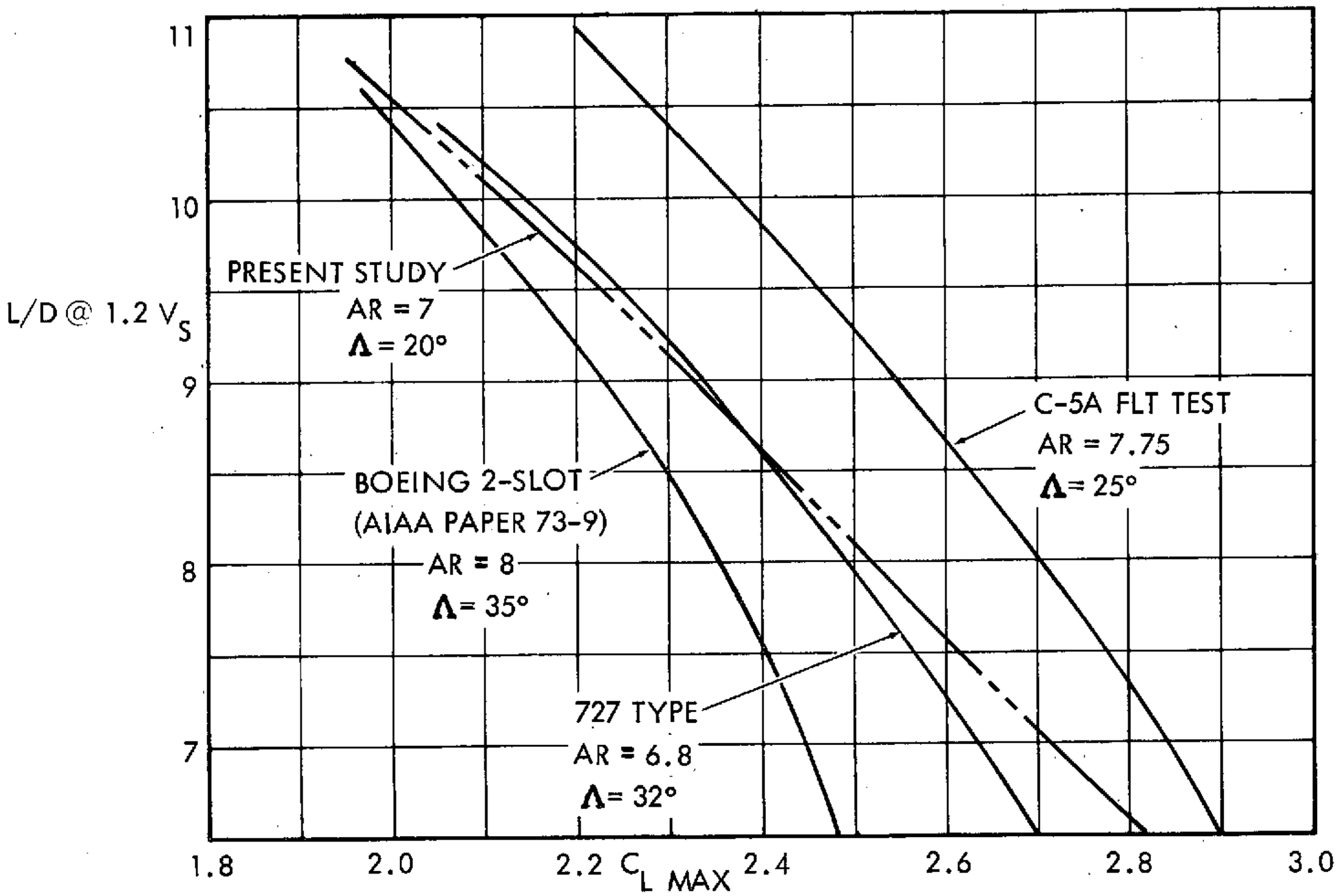


FIGURE 202: MF - LIFT AND DRAG CHARACTERISTICS OF VARIOUS MECHANICAL FLAP SYSTEMS

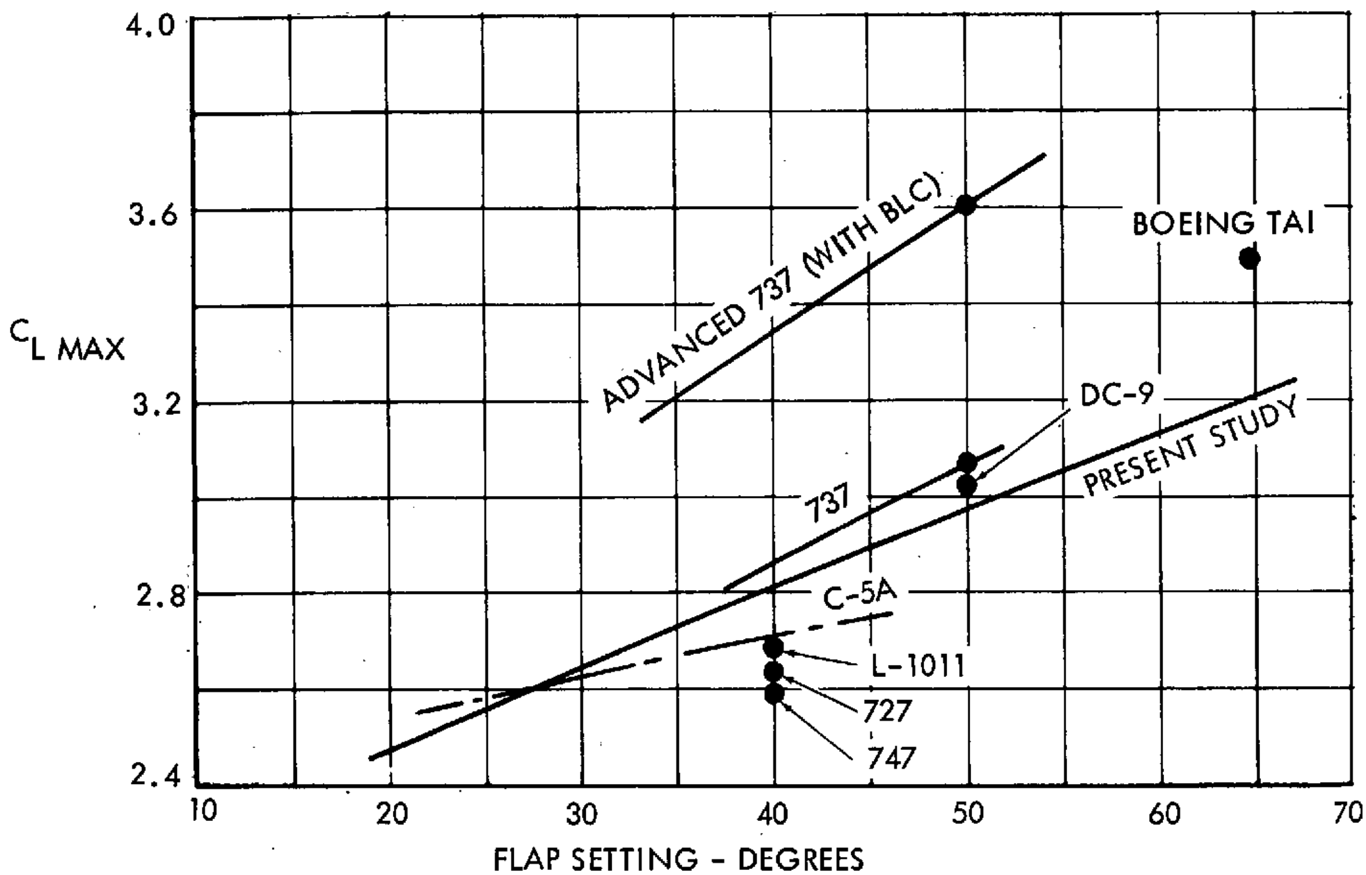


FIGURE 203: MF - COMPARISON OF $C_{L\ MAX}$ FOR VARIOUS MECHANICAL FLAPS

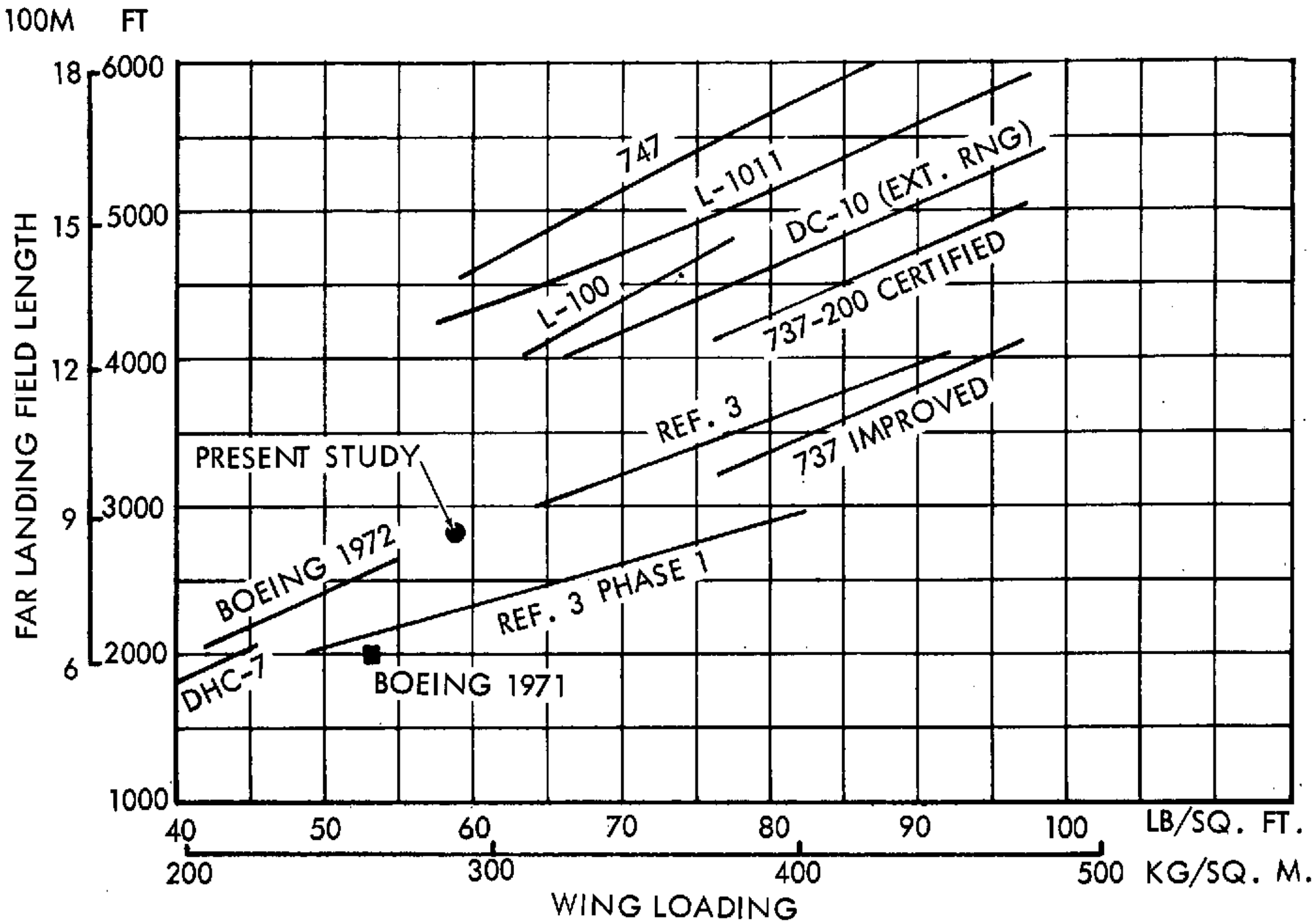


FIGURE 204: MF - FAR LANDING FIELD LENGTH COMPARISON

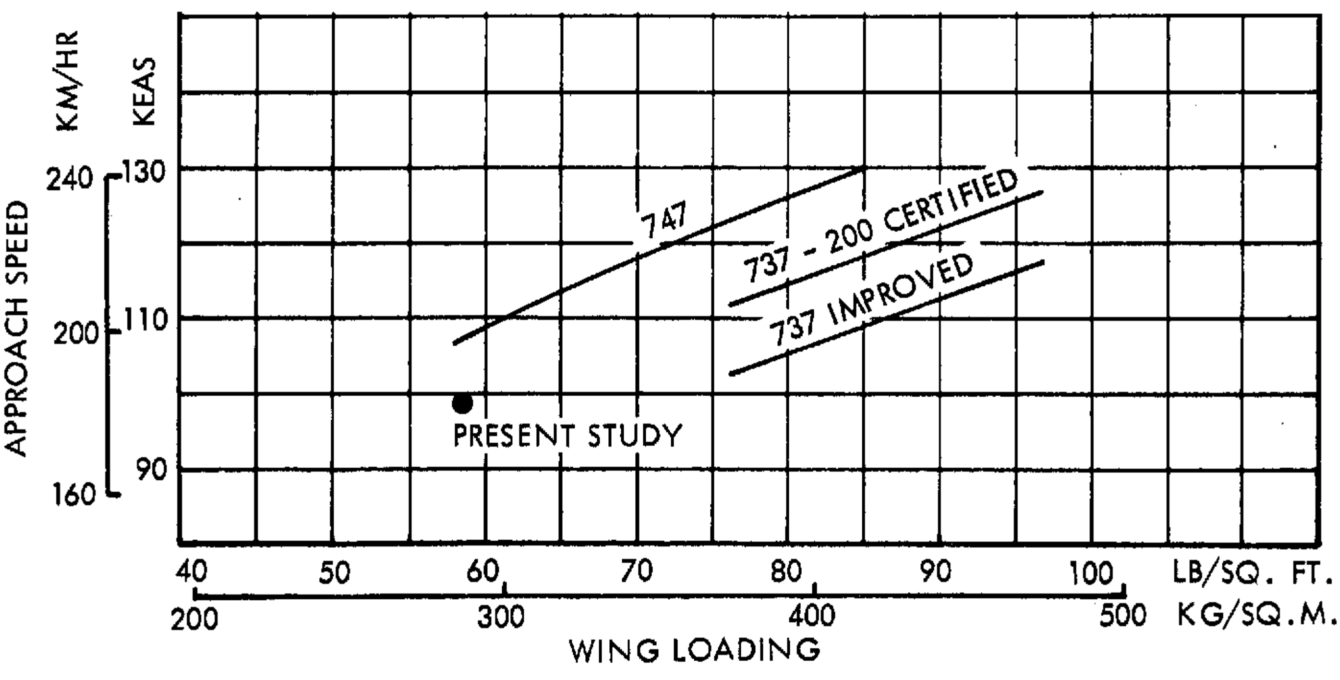


FIGURE 205: MF - APPROACH SPEED COMPARISON

6.4 MF BASELINE MISSION VEHICLES

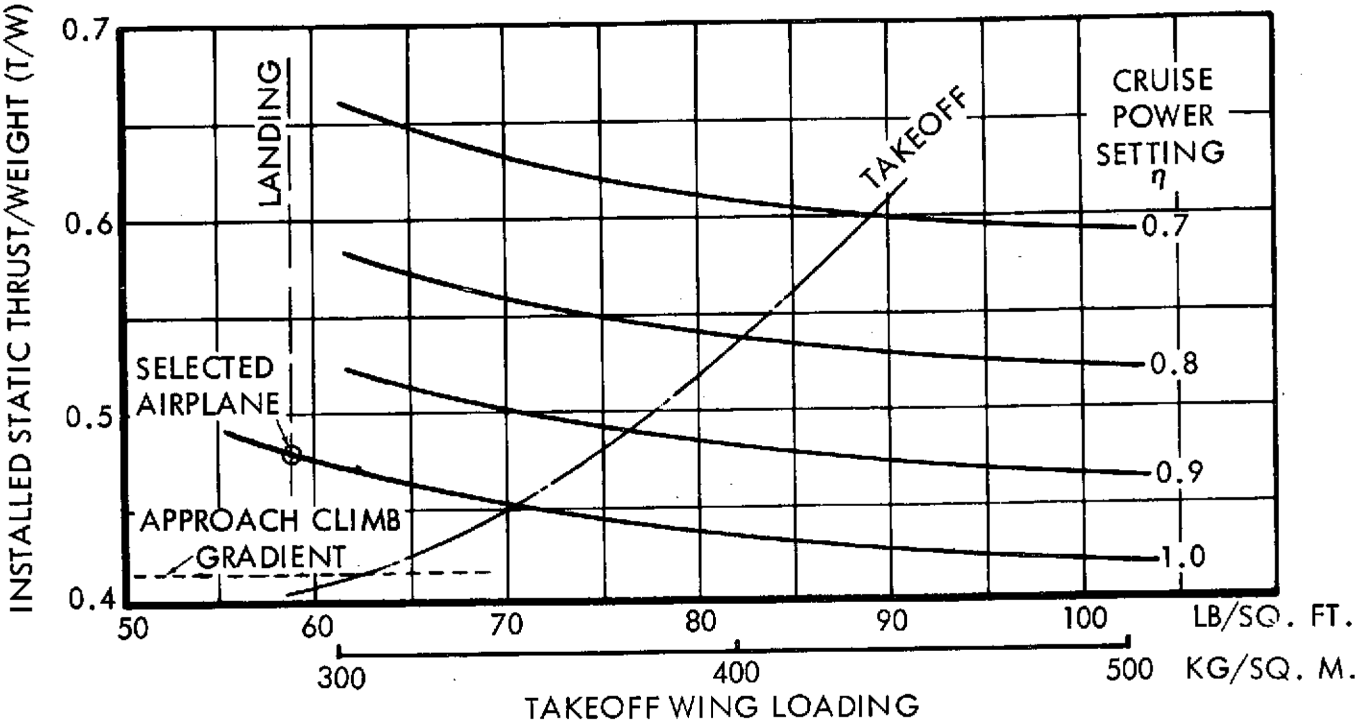
MF vehivles were configures with a low-noise engine and also with an intermediate bypass engine suitable for an advanced CTOL concept. The vehicles carried 148 passengers, over 926 Km. (500 NM) at 0.8M from and to 910m. (3000 ft.) fields. After analyzing and defining this baseline vehicle parametric sizing data for 1070m. (3500 ft.) and 1220m. (4000 ft.) vehicles were generated. This section describes the optimization procedure adopted and defines the baseline 910m. (3000 ft.) and the parametric 1070m. (3500 ft.) and 1220m. (4000 ft.) field length vehicles. The initial studies conducted used a 1.35 FPR fan engine for the low-noise configurations and a 1.574 FPR engine for the intermediate bypass configurations.

6.4.1 Optimum Number of Engines

Sizing studies have been conducted for 2, 3 and 4 engined configurations using 1.35 and 1.574 FPR engines to determine the optimum number of engines.
Figures 206 through 211 show required installed static thrust to weight (T/W) and direct operating cost plotted against takeoff wing loading (W/S) for a range of cruise power settings (η), and for the 914m. (3000 ft.) landing requirement; on the figures where takeoff is close to being critical, the 914M. (3000 ft.) takeoff requirement is also included. The DOC data plotted is based on a production run of 1500 engines irrespective of the number of engines per airplane. However, identical data have also been generated based on the number of engines required for 300 airplanes plus 25% spares, which is equivalent to 750 engines for the 2-engine configuration, 1125 for the 3-engine configuration and 1500 for the 4-engine configuration.

Since the MF is not a powered lift concept, FAR Part 25 rules apply. The particular requirement involved in these plots is the speed margin during the approach phase; FAR 25.125 requires $V_{APP} \geqq 1.3\ V_S$ whereas the value for powered lift is $V_{APP} \geqq 1.25\ V_S$. The primary effect of this requirement is to decrease landing wing loading at takeoff weight from 310 to 287 Kg./m.^{2} (63.6 to 58.8 lb./sq. ft.). It will be noted that all the configurations are landing field length critical;

910M (3000 FT.) FIELD LENGTH



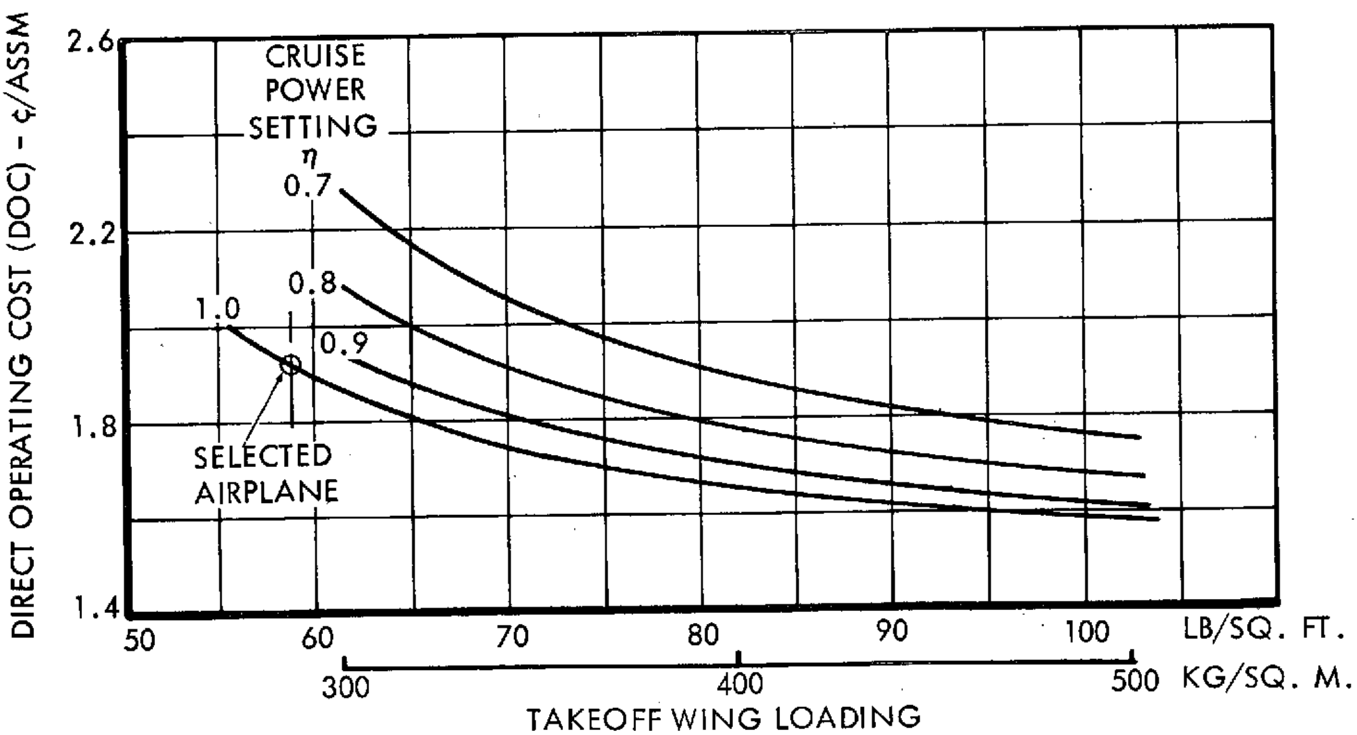
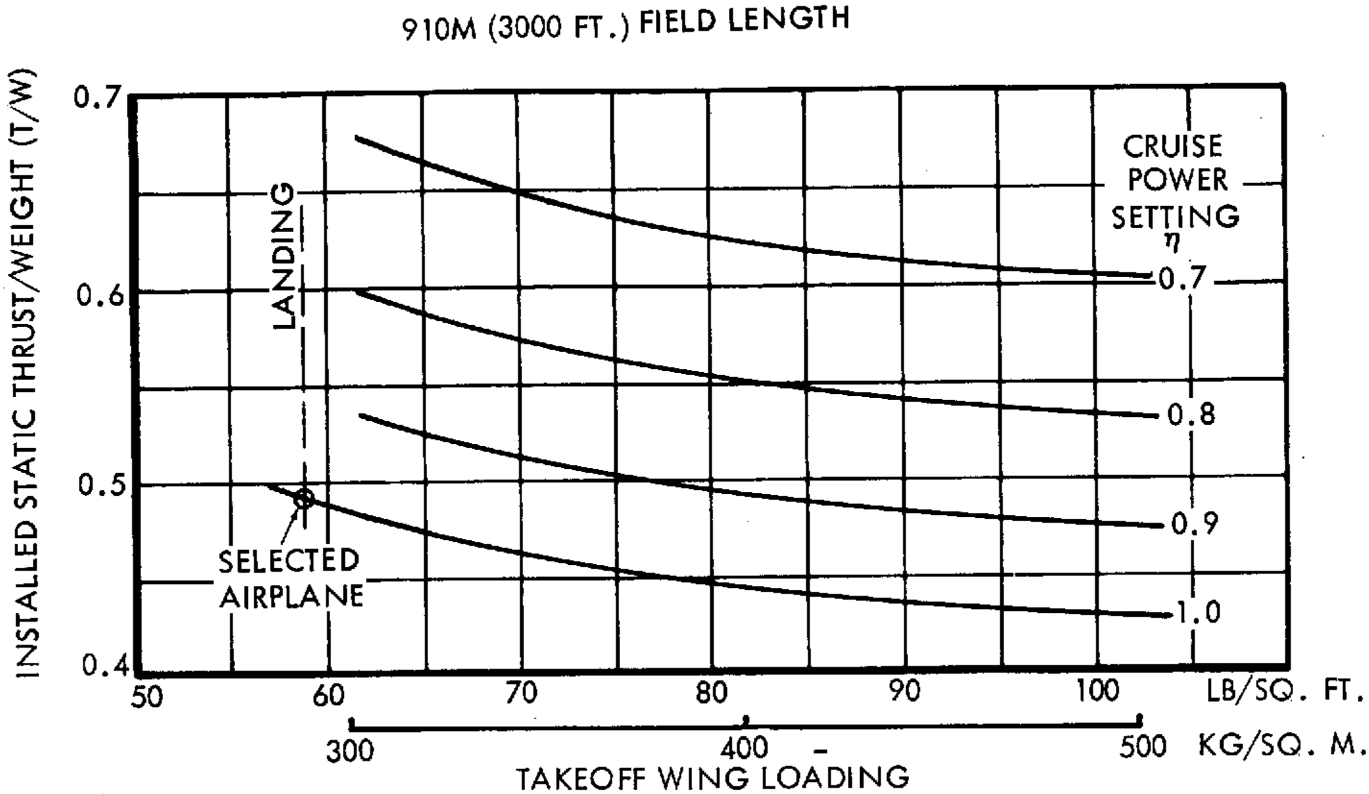


FIGURE 206: 2-ENGINE MF, 1.35 FPR SIZING DATA



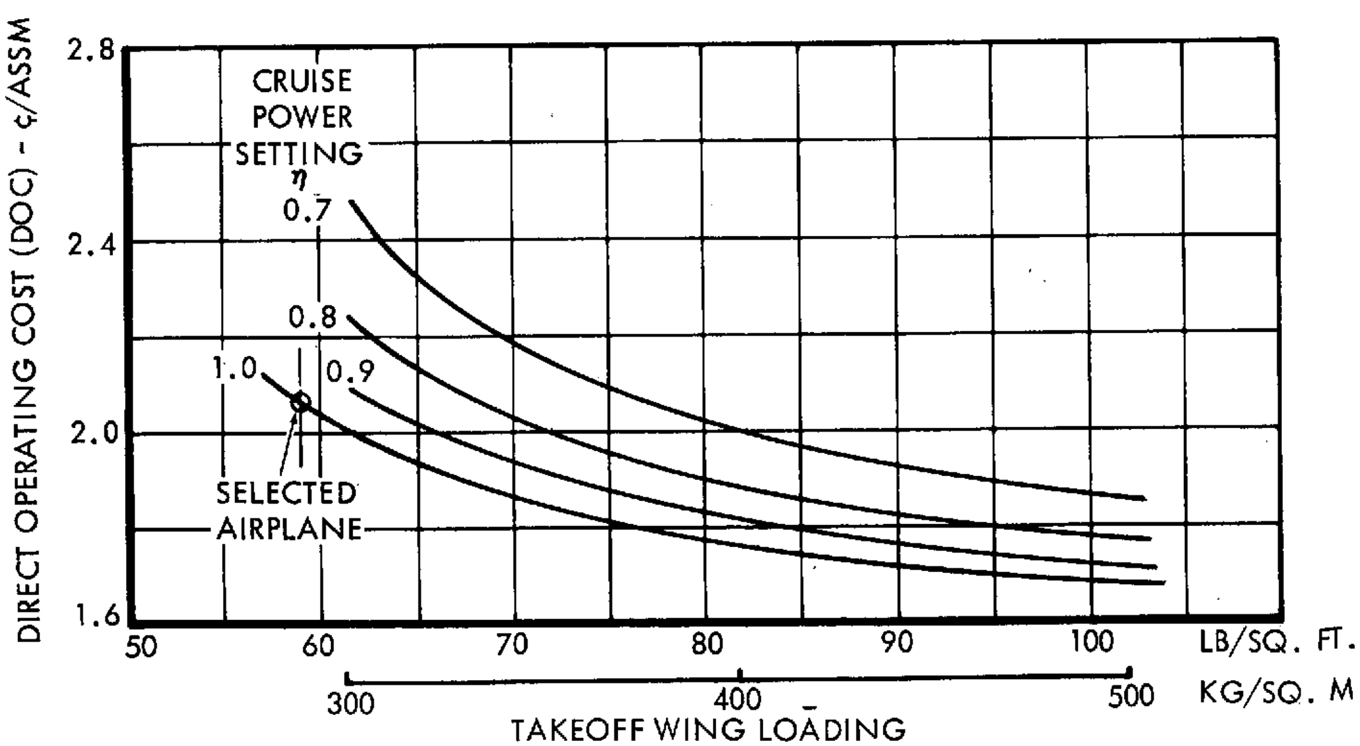
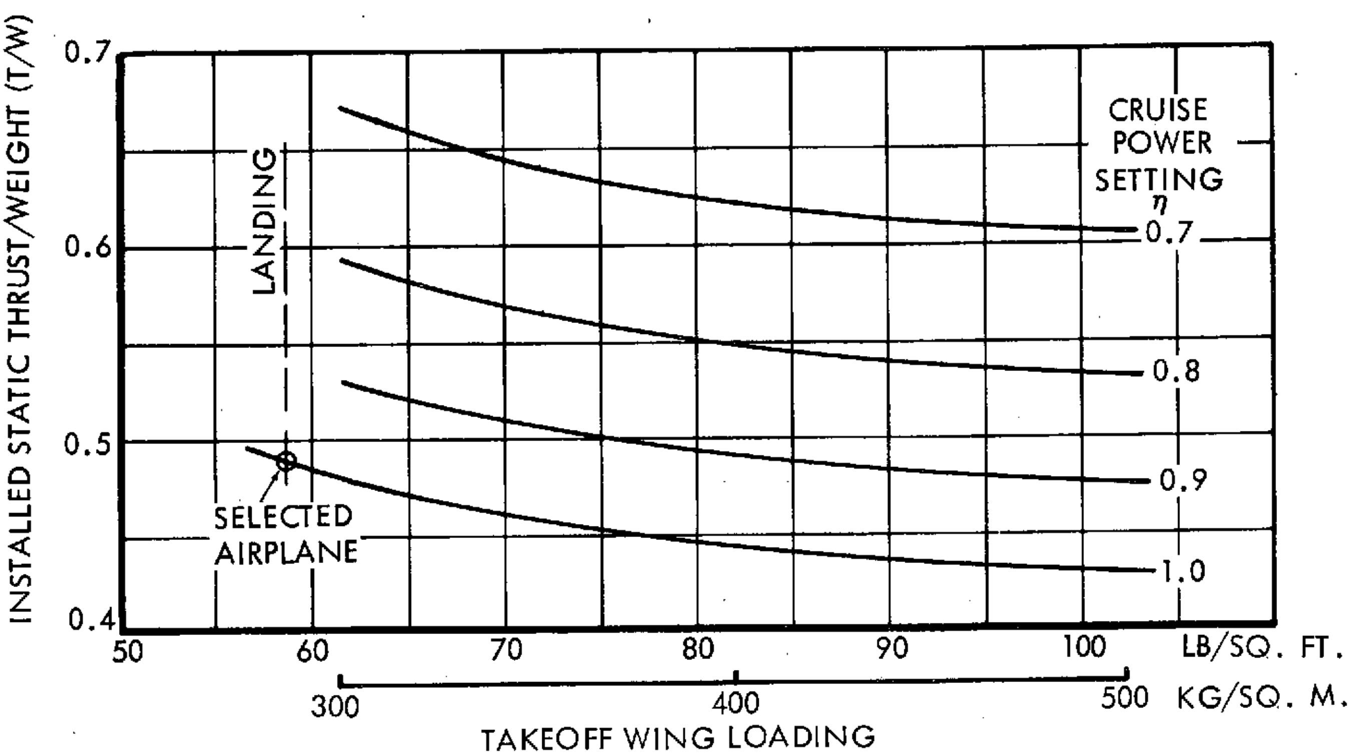


FIGURE 207: 3-ENGINE MF, 1.35 FPR SIZING DATA

910M (3000 FT.) FIELD LENGTH



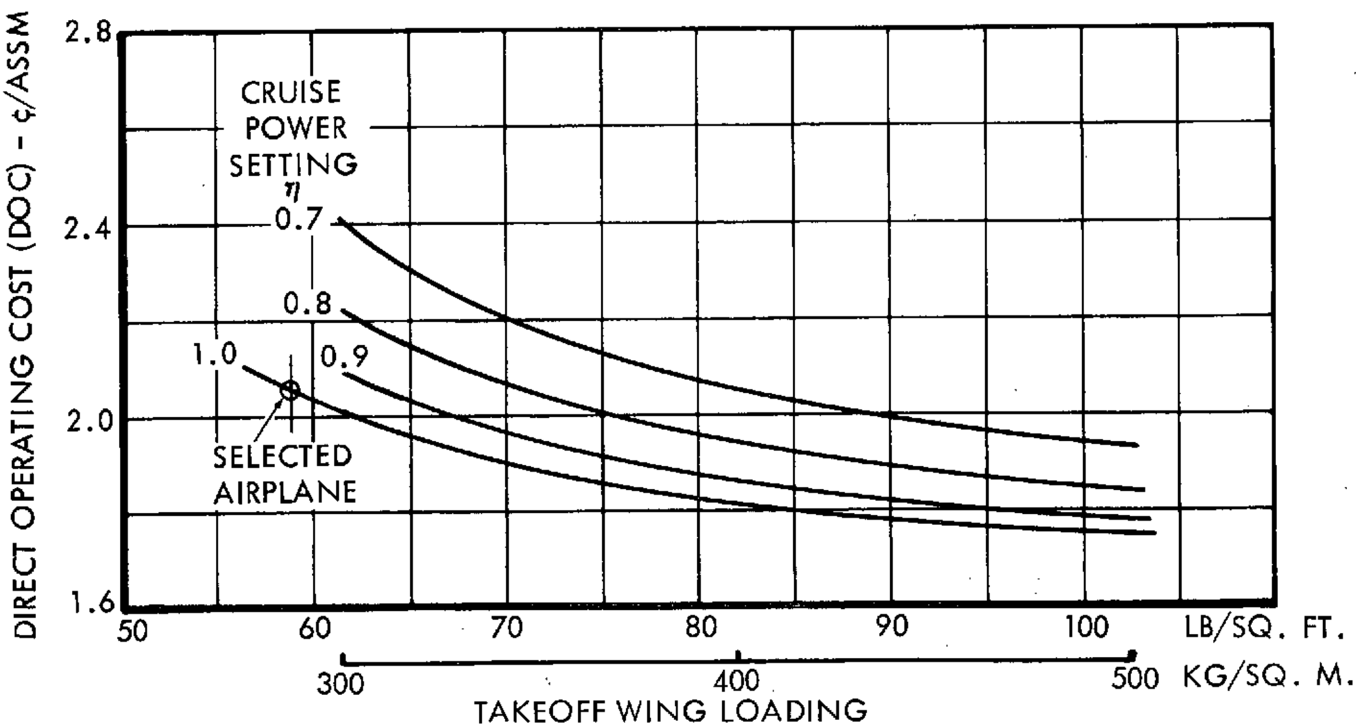
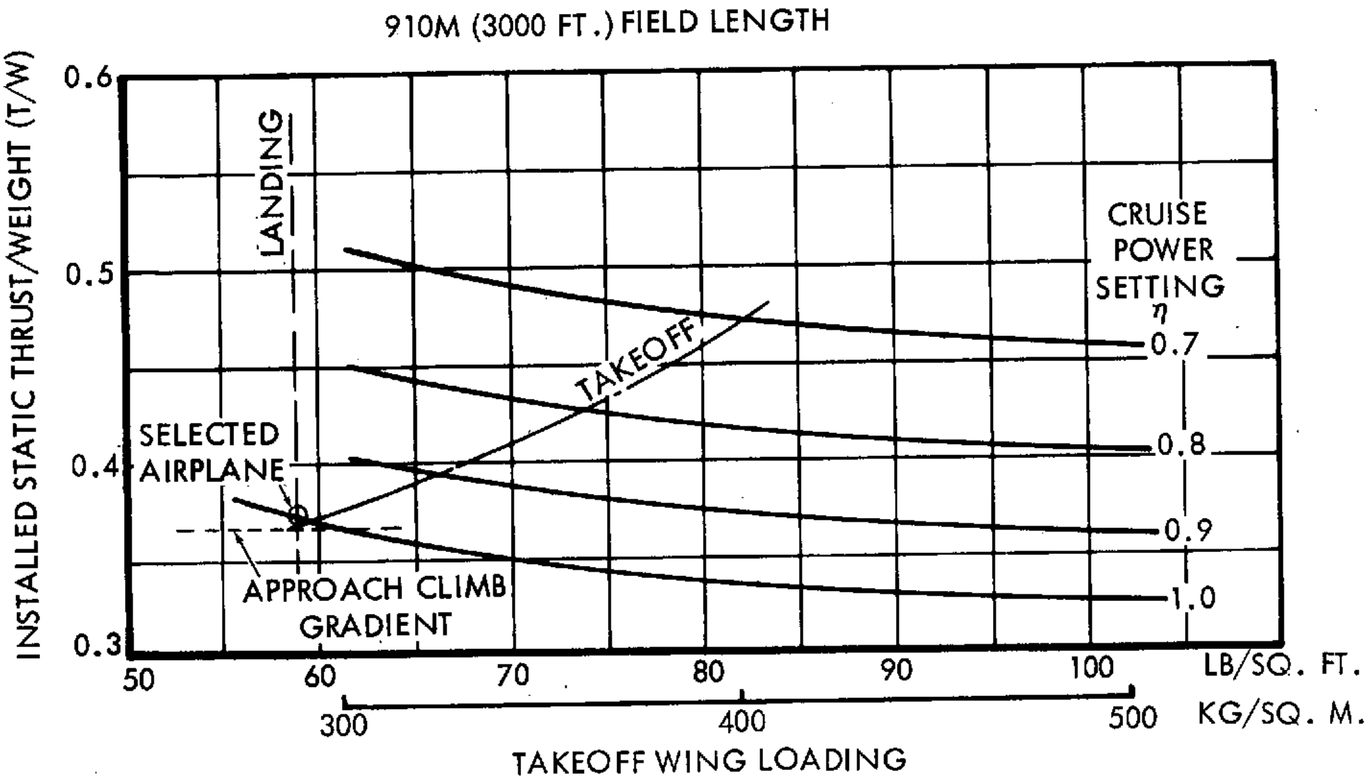


FIGURE 208: 4-ENGINE MF, 1.35 FPR SIZING DATA



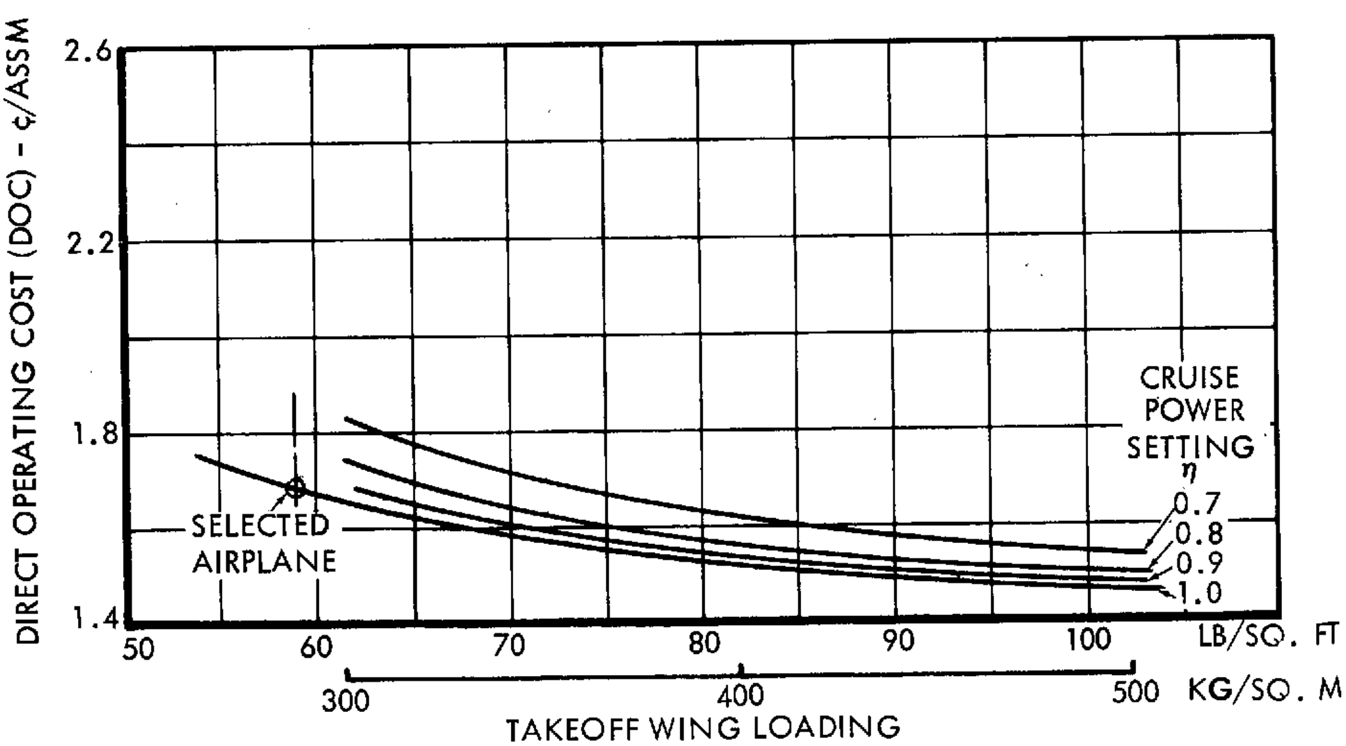


FIGURE 209: 2-ENGINE MF, 1.574 FPR SIZING DATA

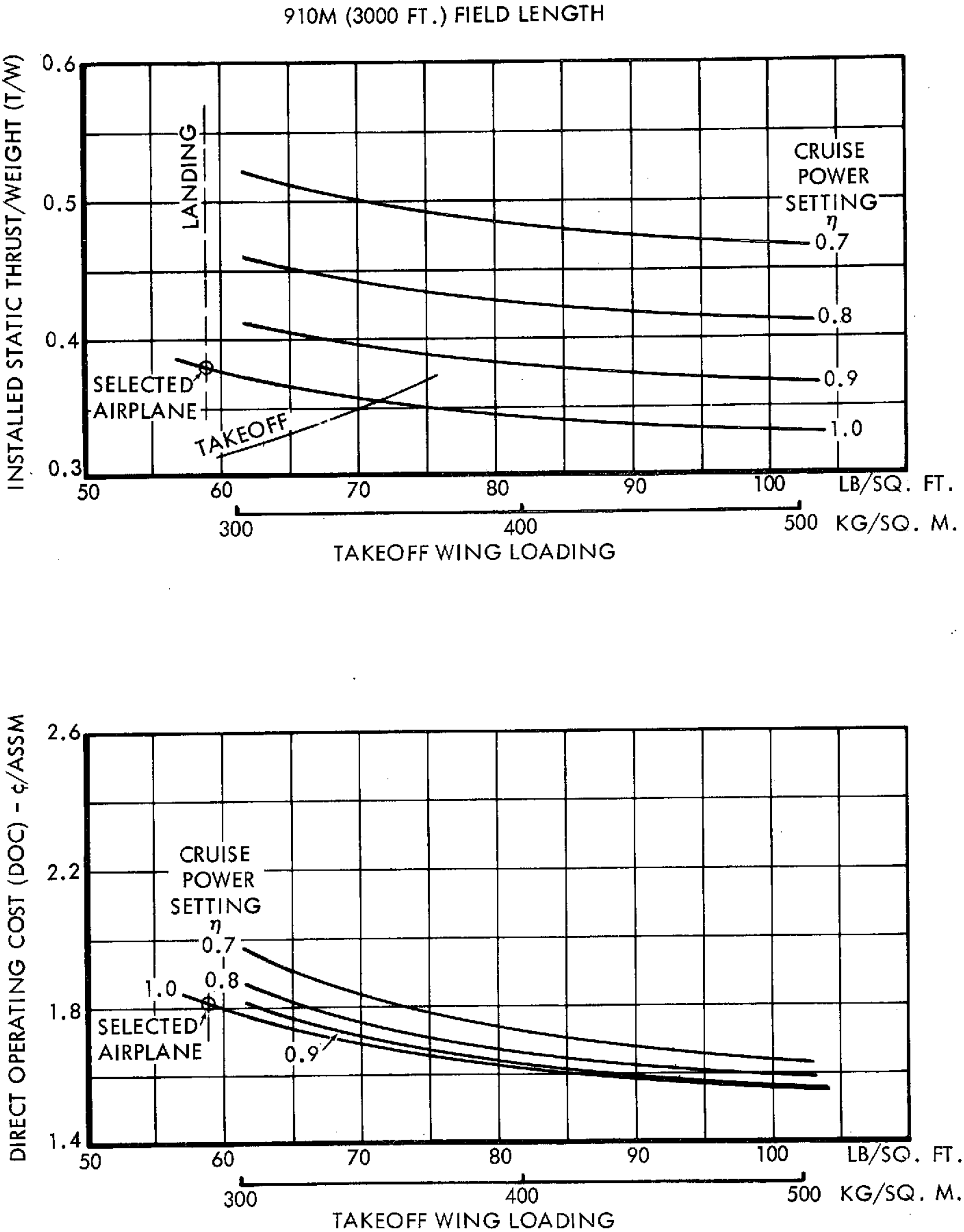
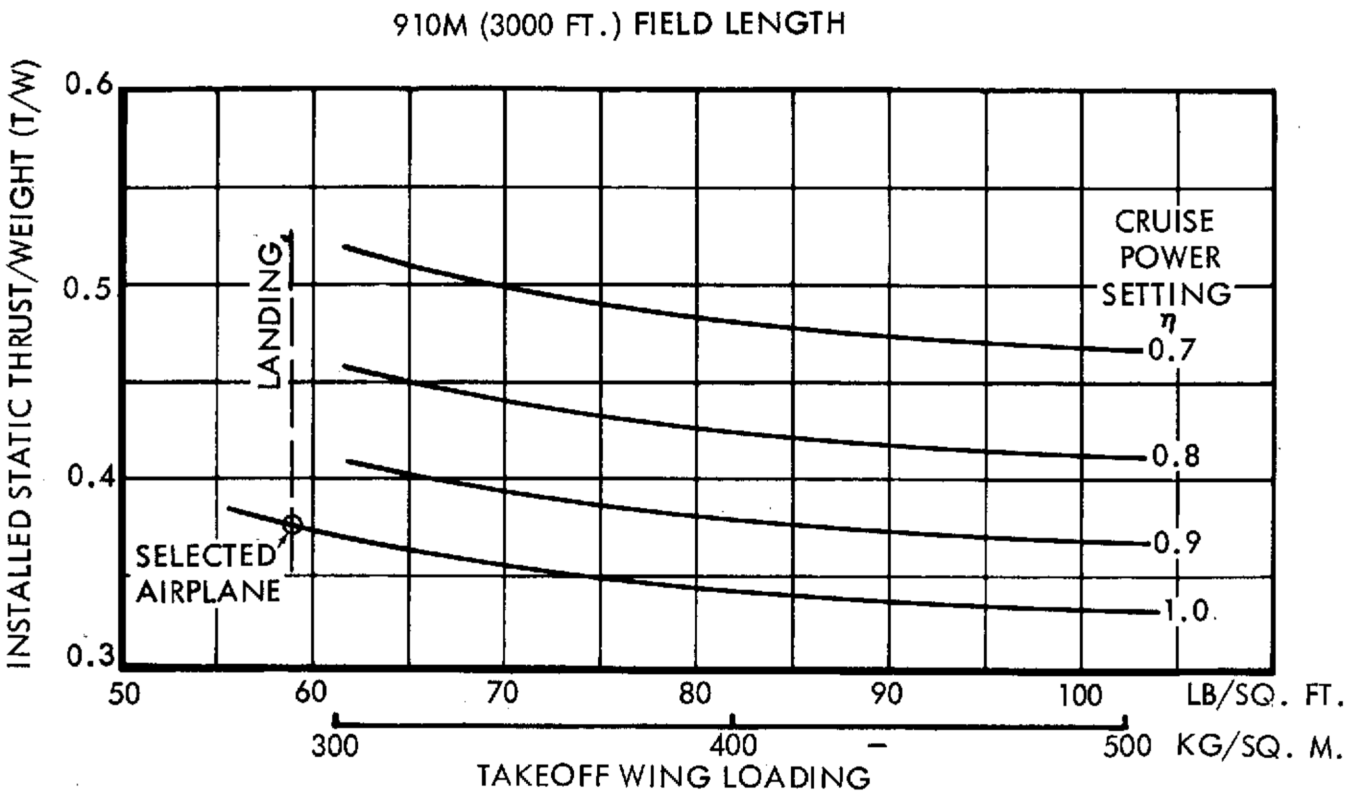


FIGURE 210: 3-ENGINE MF, 1.574 FPR SIZING DATA



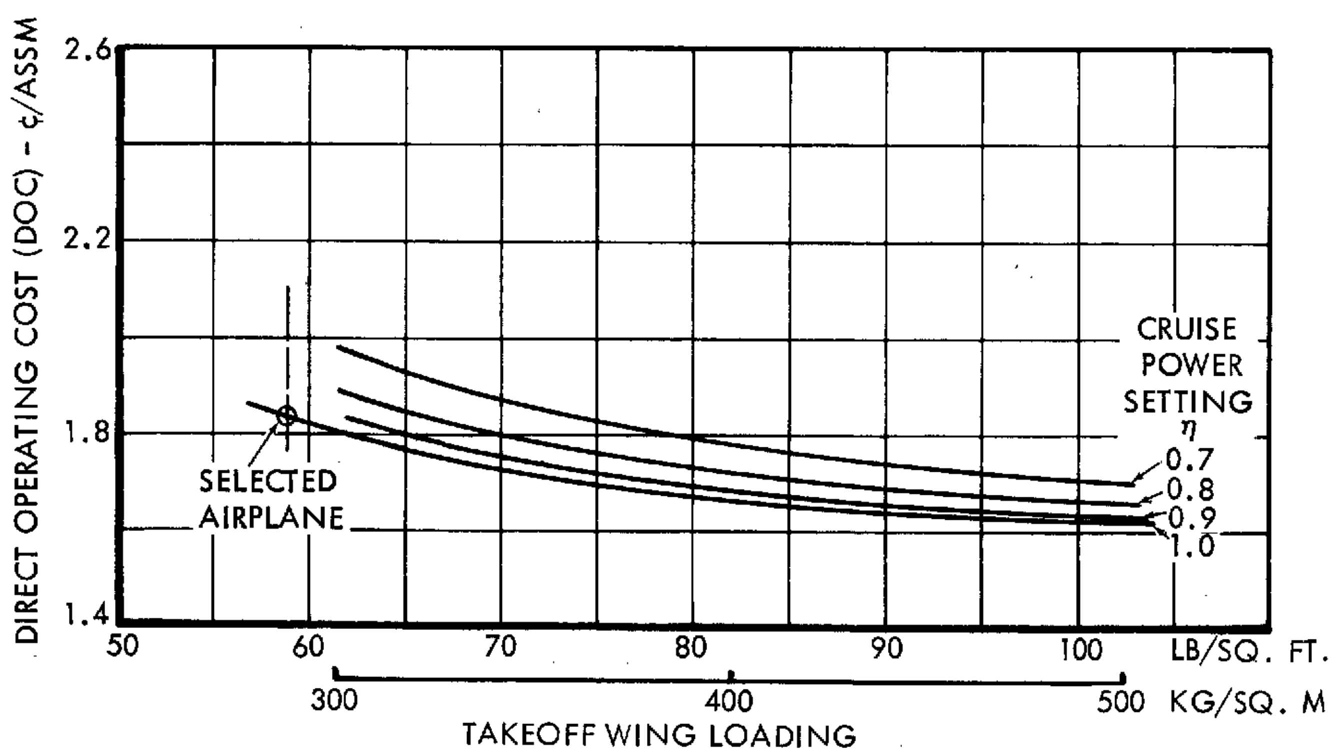
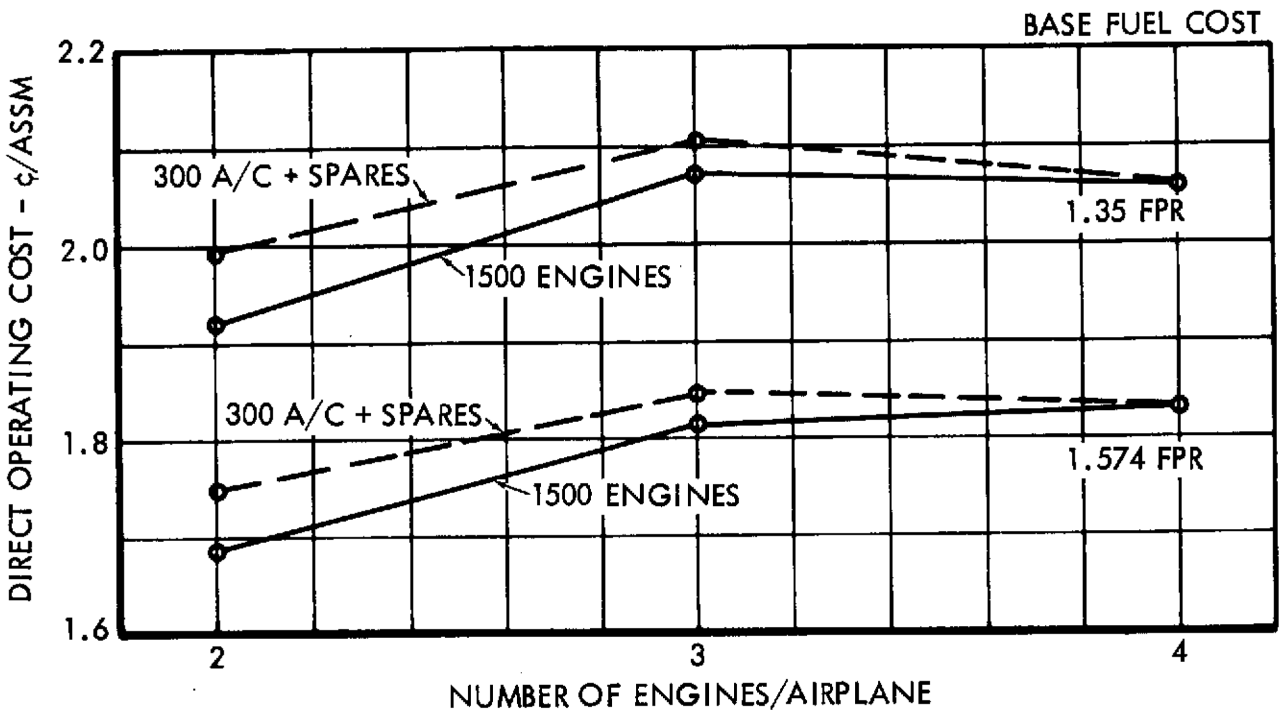


FIGURE 211: 4-ENGINE MF, 1.574 FPR SIZING DATA

the 2-engine FPR 1.574 configuration shown in Figure 209 is also close to being climb gradient critical in the approach configuration. Minimum DOC is obtained at a takeoff wing loading of 287 Kg./m.^{2} (58.8 lb./sq.ft.) for all configurations and a cruise power setting of 1.0 (i.e. 100% cruise power).

To determine the sensitivity of the selection of the number of engines to fuel cost, the data shown in Figure 212 were generated. In this plot the cost of fuel has been doubled relative to the fuel cost used in the upper portion of the figure. This change in fuel cost has increased all the DOC's by approximately 17% but has not changed the choice of optimum number of engines per airplane. Later studies confirmed this conclusion for even higher fuel costs. It should be noted that for this analysis the sizing routine used was identical to that used in Reference 2 and does not reflect data improvements developed during the study; the absolute values of DOC should not therefore be expected to agree precisely with data included elsewhere in the report. The minimum DOC data for each configuration is plotted in the upper portion of Figure 212 for the alternate engine production quantity bases. For both FPR's and both quantity bases, the two-engine configurations have lower DOC's than the 3- and 4-engine arrangements. It can be concluded that for FPR's between 1.35 and 1.574 the 2-engine configuration is the optimum.

Tables XXV and XXVI compare the primary characteristics of the 2, 3 and 4-engined airplanes with 1.35 FPR and 1.574 FPR engines. The two-engined configurations are slightly heavier than the 4-engined configurations, due to the higher aspect ratio wing but this is offset in the DOC calculation by the lower cost per pound of thrust of the larger thrust engines compared with the smaller thrust engines of the four-engined arrangements, even allowing for differences in the production quantities of the engines. Figure 213 shows the engine cost basis and is discussed later in this section. The three-engined configurations are heavier than either the two-engined or four-engined configurations, due primarily to the more aft location of the wing on the three-engined arrangement resulting in a shorter tail-arm and hence larger tail surfaces.



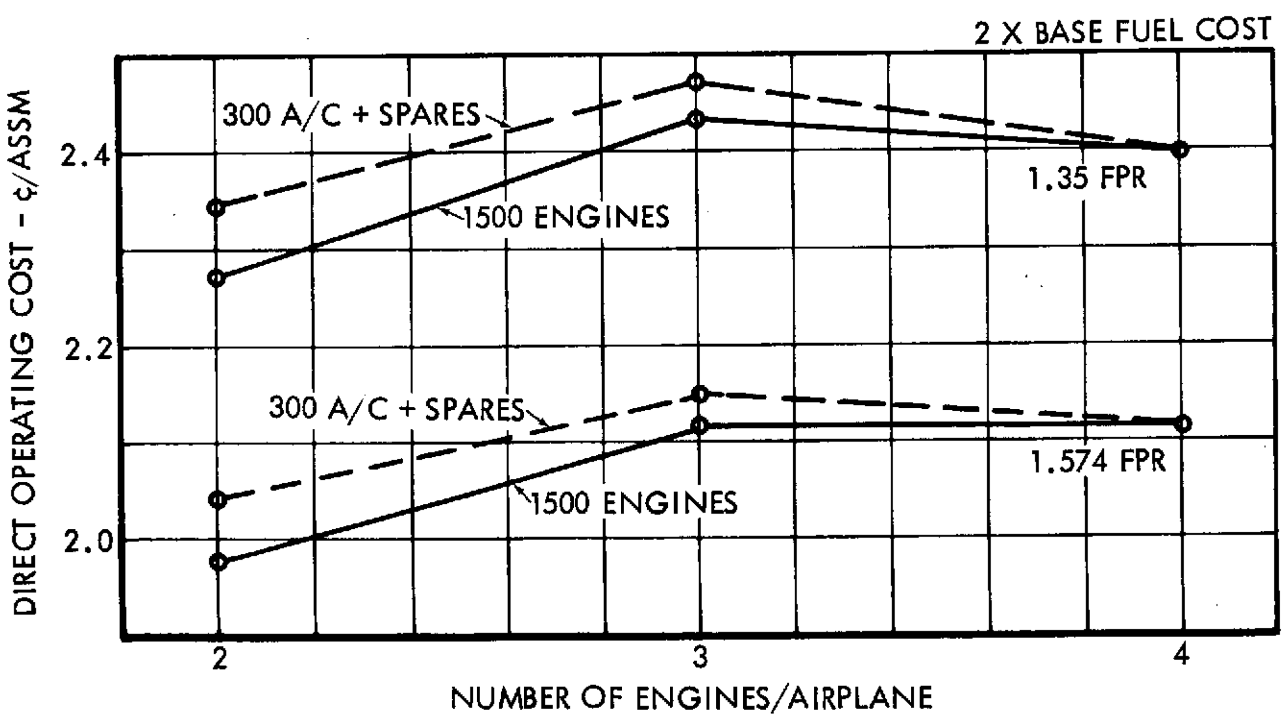


FIGURE 212: DIRECT OPERATING COST VS NUMBER OF ENGINES (MF)

	NUMBER OF ENGINES		
	2	3	4
W/S T.O. - LB/SQ. FT.	58.8	58.8	58.8
INST. T/W (T.O.)	0.482	0.492	0.488
AR	7.0	6.75	6.5
RGW - LB	176,500	181,500	169,500
OWE - LB	121,200	126,300	115,000
RATED THRUST/ENGINE - LB.	46,600	32,700	22,600
500 N.M. MISSION FUEL - LB.	17,700	18,500	17,200
DOC - ¢/ASSM	1.992	2.107	2.06

148 PAX; 0.8M; 910M (3000 FT.) FIELD LENGTH

300 AIRCRAFT PRODUCTION

TABLE XXV: MF - COMPARISON OF 2, 3 AND 4 ENGINE CONFIGURATION CHARACTERISTICS, FPR 1.35

	NUMBER OF ENGINES		
	2	3	4
W/S T.O. - LB/SQ. FT.	58.8	58.8	58.8
INST. T/W (T.O.)	0.323	0.38	0.375
RGW - LB	153,000	156,850	147,600
OWE - LB	103,000	105,400	98,000
RATED THRUST/ENGINE - LB	31,400	22,000	15,400
500 N.M. MISSION FUEL - LB	14,600	15,100	14,250
DOC - ¢/ASSM	1.748	1.847	1.83

148 PAX; 0.8M; 910M (3000 FT.) FIELD LENGTH

300 AIRCRAFT PRODUCTION

TABLE XXVI: MF - COMPARISON OF 2, 3 AND 4 ENGINE CONFIGURATION CHARACTERISTICS, FPR 1.574

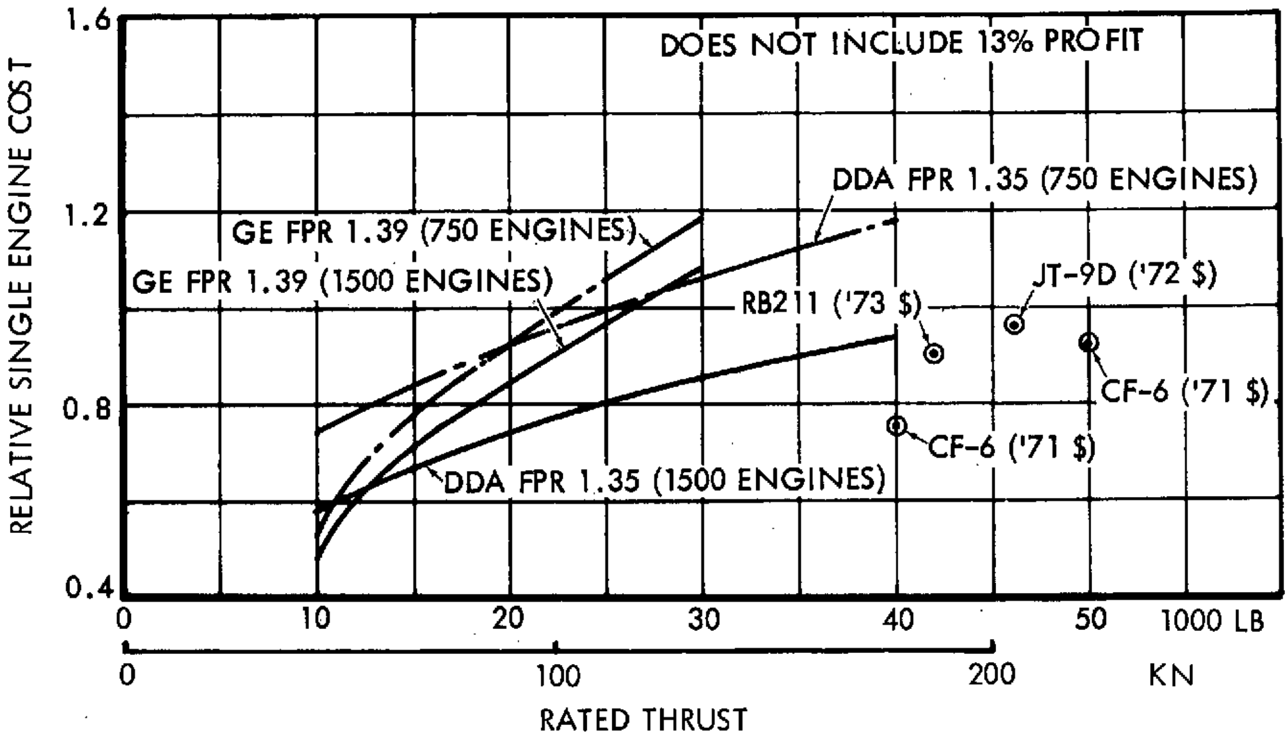


FIGURE 213: ENGINE COST BASIS

The effect of using 1500 engines as the production quantity for the engine cost basis rather than engine quantity for 300 aircraft is also shown in Figure 212 . This increases the advantage of the two-engined airplane over the other configurations. Single-engine cost versus uninstalled rated thrust is shown in Figure 213 based on Detroit Diesel Allison (DDA) data and General Electric (GE) data. Actual costs proposed to Lockheed for the CF-6, RB211 and JT-9D have also been plotted for comparison. Since the DDA and GE data are similar at the 57.8 KN (13,000 lb.) thrust level and the DDA data correlates very well with the actual quoted engine costs at the higher levels, the DDA data have been used as the cost basis throughout the program. In comparing the engine costs quoted for sized airplanes with this data, it should be noted that 13% profit is added to the basic engine cost data when installed in the airplane. The DDA engine cost is a function of thrust to the 0.35 power, while the GE engine cost is a function of thrust to the 0.6 power. An examination of historical engine data and of a Rand analysis (Reference 34) indicates that the 0.6 exponent (0.612 in Rand) has been applicable in the past to engine prices in a more-or-less uniform family, although the current experience with CF-6, RB-211 and JT9-8 engine prices seems to lower this trend. Analysis of the 2, 3 and 4 engine airplanes shows that the selection of the 2-engine configuration is unchanged if the GE pricing is used, even if the pricing is based on 750 engines.

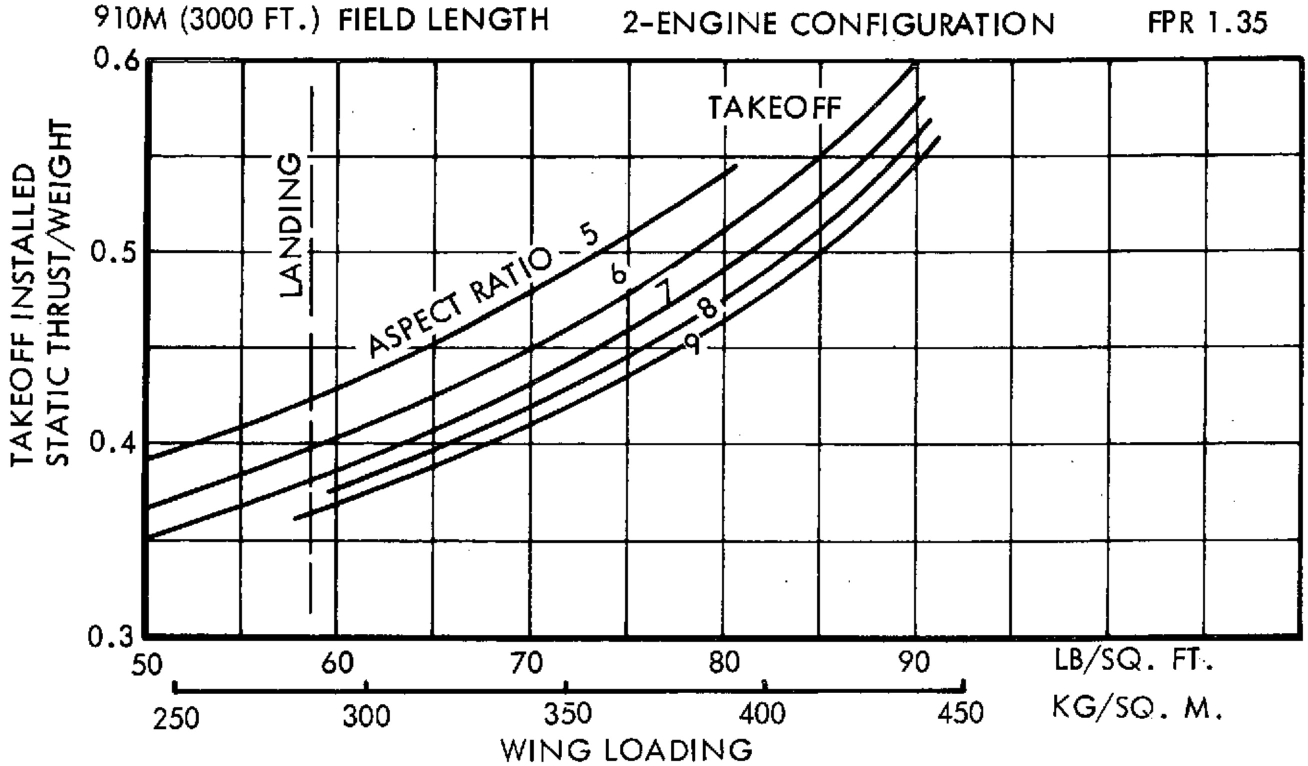
6.4.2 Optimum Aspect Ratio and Sweepback

The initial studies reported in Section 6.4.1 were conducted using the Ref. 2 engine data and care should be exercised in comparing them with the following data which incorporates a number of modifications as explained in the text and figures. The primary modification is the use of nacelles with only wall noise treatment as noted in Section 6.2. Other changes include the use of engine bleed for the environmental control system rather than an APU, changes to the nacelle costing equations to account for the modified noise treatment, an increase in the level of supercritical wing technology (0.08 DDM rather than 0.065) and a slightly modified wing weight equation to better account for lower aspect ratio wings and to match the detailed wing weight estimates made in Ref. 2.

Figure 214 presents the effect of aspect ratio on thrust and wing loading required for twin-engined configurations with 1.35 and 1.574 fan pressure ratio engines. No correction for sweep variation has been included for the reasons discussed in Section 6.3 To meet the 914m. (3000 ft.) landing field length, an approach speed of 182.2 Km/hr. (98.4 knots) is required which in turn necessitates a wing loading of 287 Kg/m.^{2} (58.8 lb./sq. ft.) irrespective of the thrust-to-weight ratio available. To meet the takeoff and landing field length for a particular aspect ratio, the wing loading is determined by the landing requirement as 287 Kg/m.^{2} (58.8 lb./sq. ft.) and the T/W is determined by the takeoff distance requirement. Second segment climb gradient is not a problem; however, for some combinations of aspect ratio and fan pressure ratio the T/W required to meet the go-around 2.1 percent climb gradient requirement of FAR 25.121 (d) in the approach configuration is critical. Figure 215 presents the T/W required to meet this gardient requirement plotted against aspect ratio. Figure 216 shows T/W required to provide the 2.1 percent approach gradient at speeds from 1.2 to 1.5 V_S for an aspect ratio 7.0 wing and FPR 1.35 and 1.574 engines. FAR permits the use of climb speeds up to 1.5 V_S and since the figure shows that this speed requires the minimum T/W, it was used in generating the data presented in Figure 215.

Sample sizing plots showing the relative criticality of takeoff and landing distance, approach climb gradient and cruise in determining the T/W required are presented in Figures 217 and 218 for FPR 1.135 and FPR 1.574 engines respectively. As can be seen from Figure 217, the minimum T/W meeting all the requirements is 0.458, the critical requirement being cruise at 100% power. The effect of using FPR 1.574 engines can be seen by comparing the critical case of Figure 217 with the data presented in Figure 218. With the FPR 1.574 engine, the minimum T/W which meets all requirements is 0.39. The critical requirement in this case is the approach climb-out gradient, followed by the takeoff field length with cruise least critical of all, but still close to being critical.

The foregoing examples are for aspect ratio 6 and 0.25c sweepback of 15°. Similar data were generated for each of the following combinations of aspect ratio and sweepback for both FPR's.



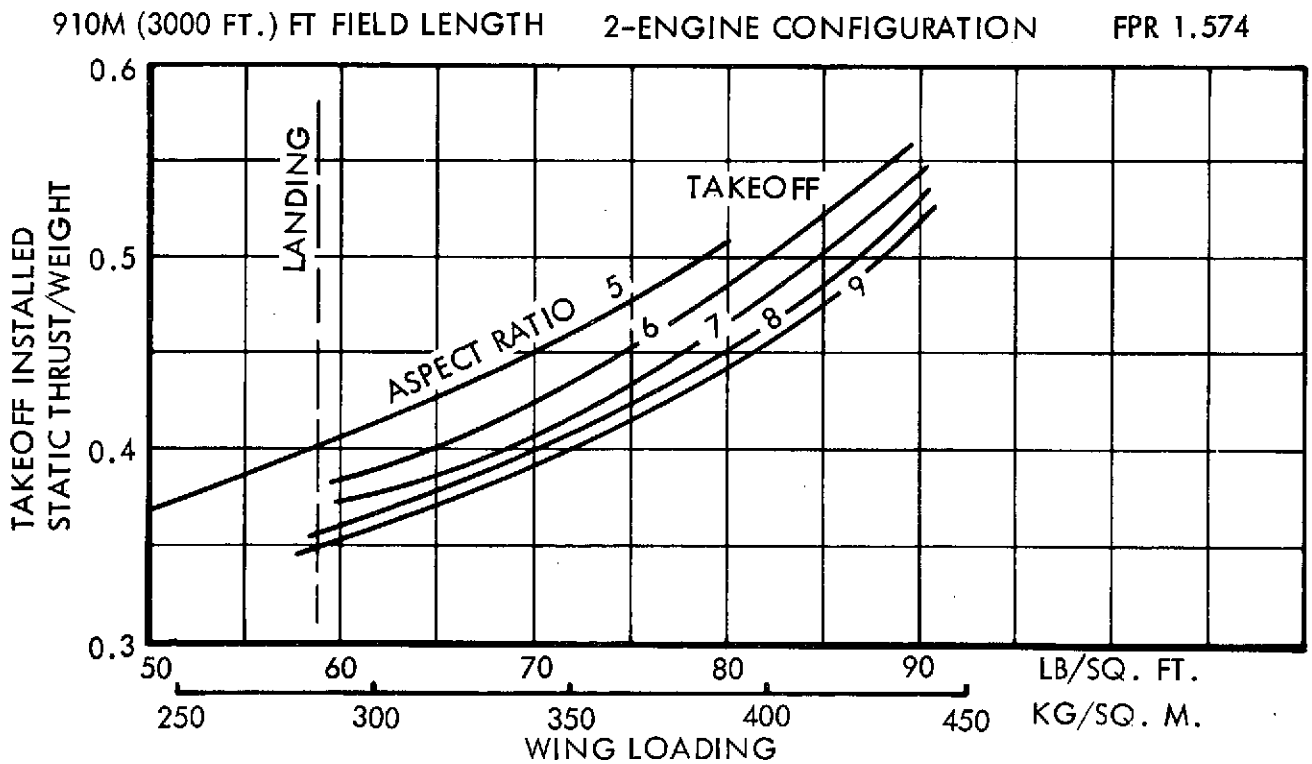


FIGURE 214: MF - T/W REQUIRED FOR TAKEOFF AND LANDING VS W/S AND AR

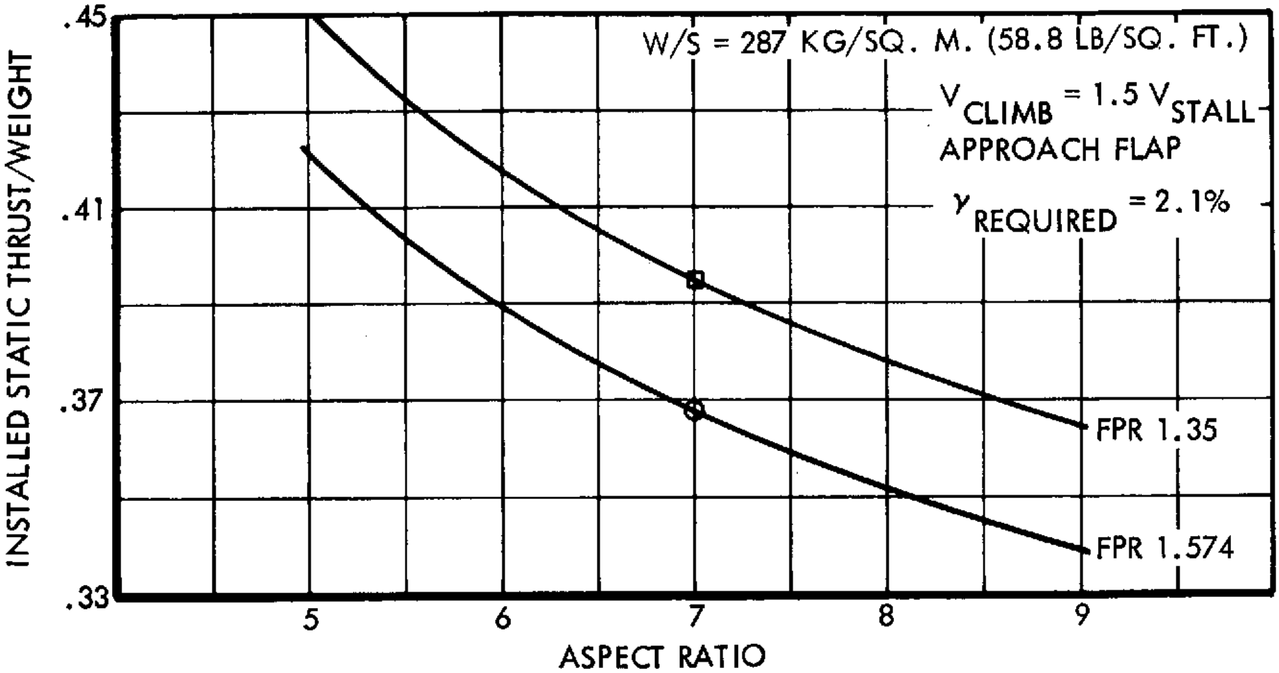


FIGURE 215: MF- T/W REQUIRED TO MEET APPROACH CLIMB GRADIENT REQUIREMENT

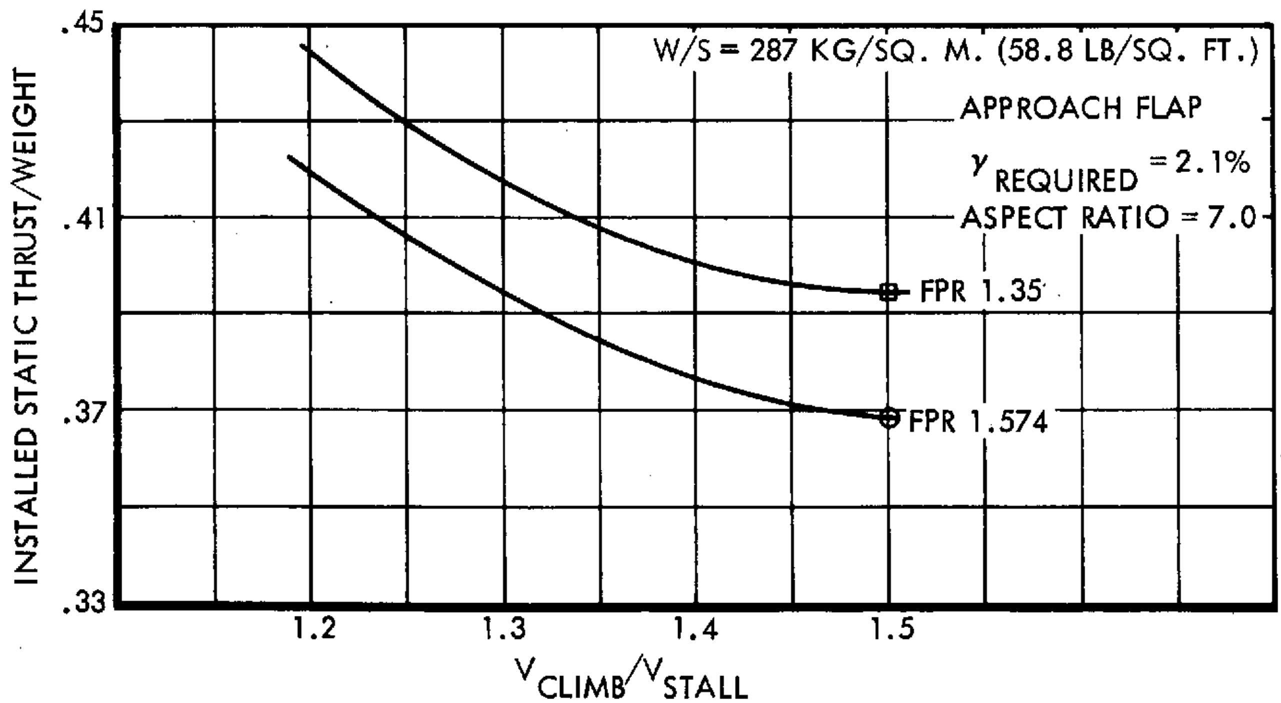
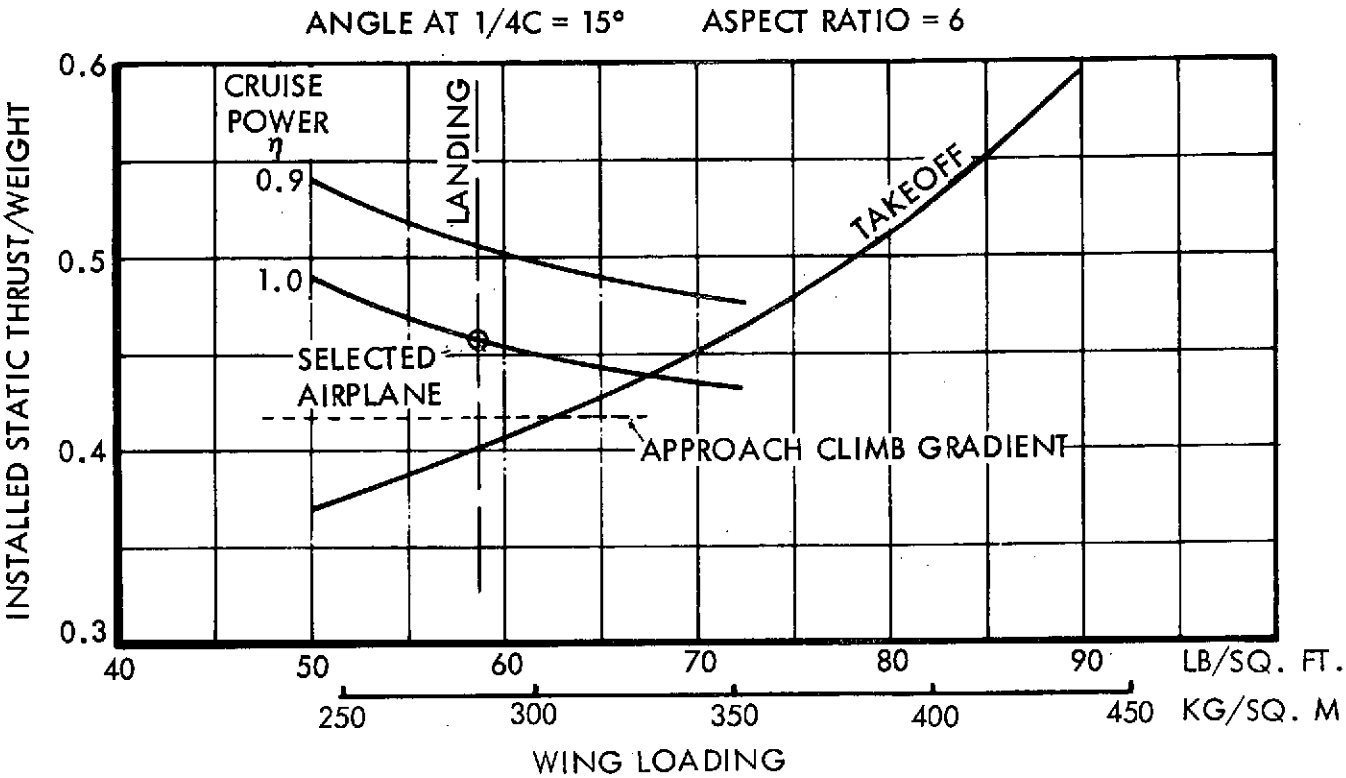


FIGURE 216: MF- T/W REQUIRED VERSUS CLIMB SPEED TO MEET APPROACH CLIMB GRADIENT REQUIREMENT



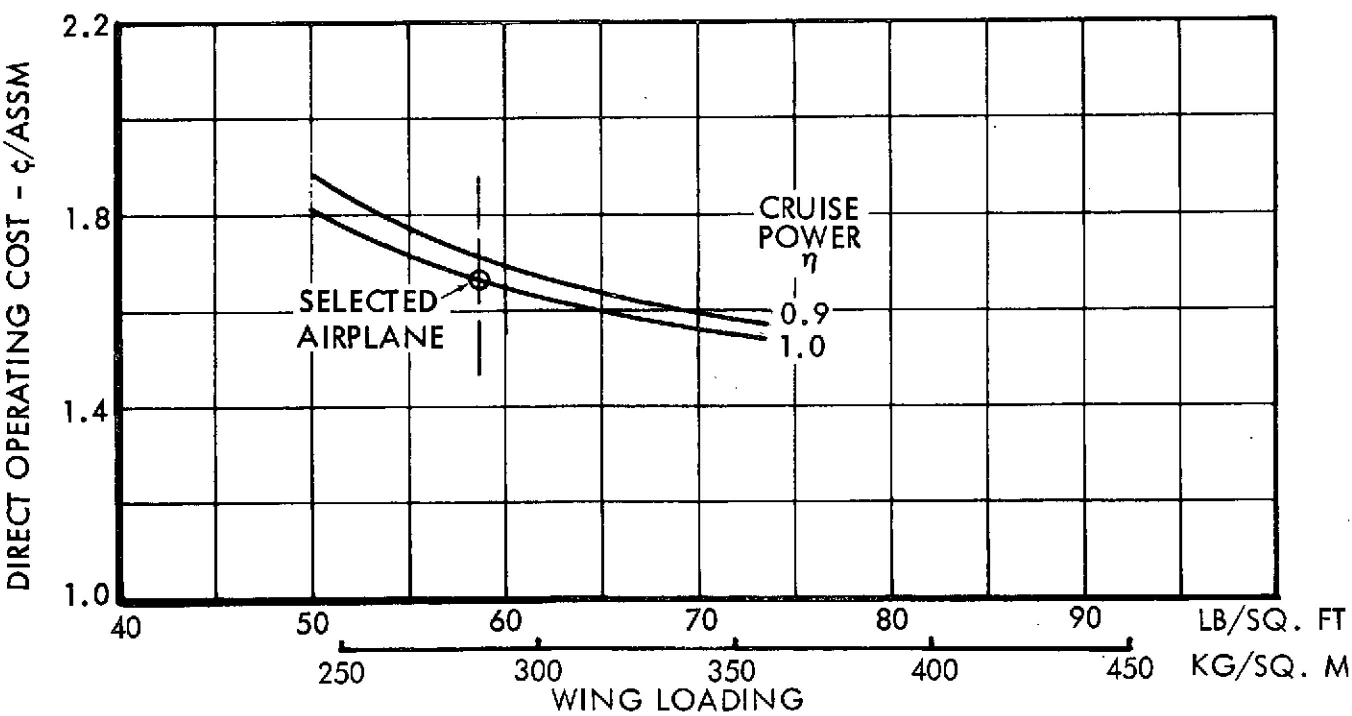


FIGURE 2.17: MF–T/W AND DOC VS W/S $_{T.O.}$ (FPR 1.35)

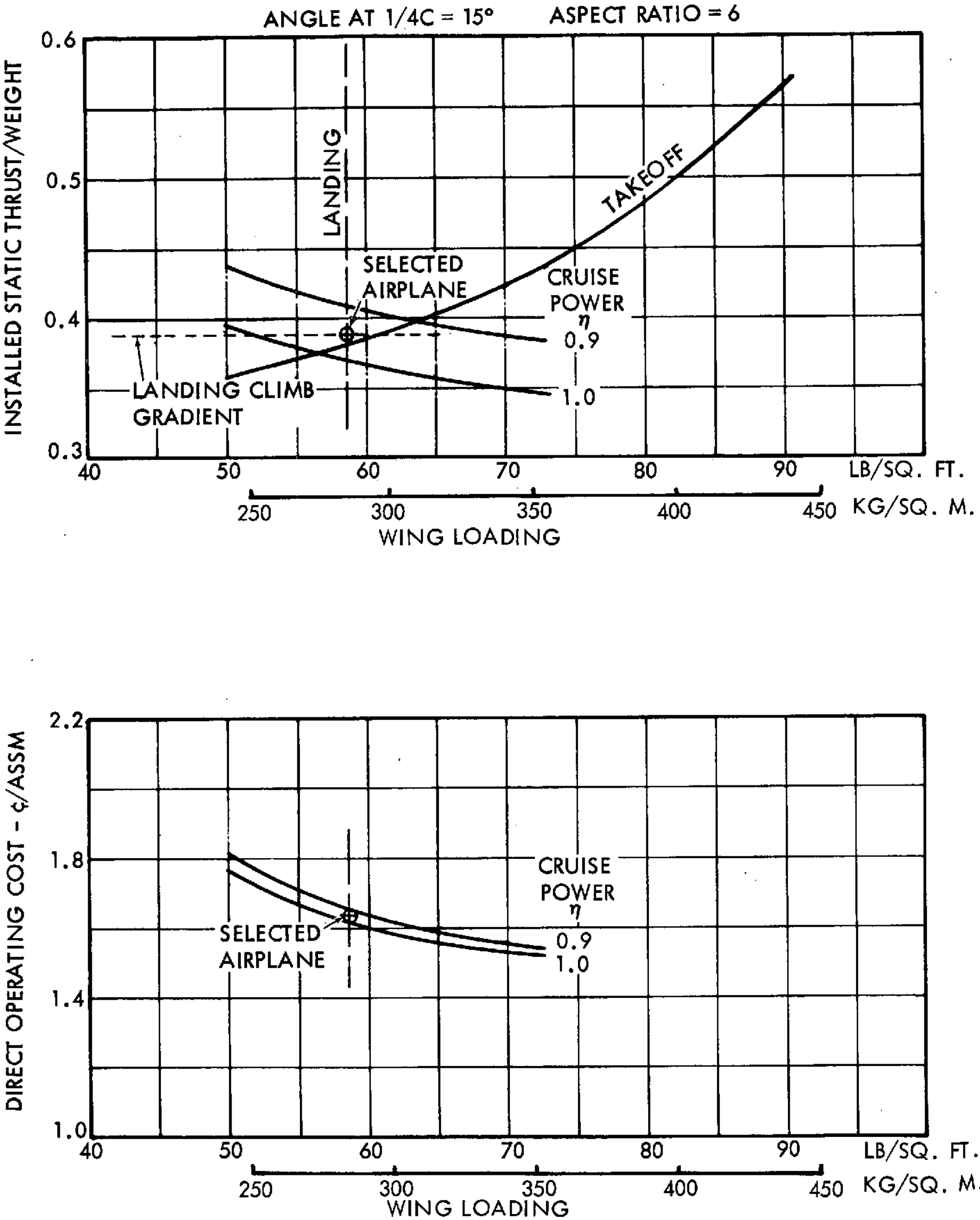


FIGURE 218: MF–T/W AND DOC VS W/S $_{T.O.}$ (FPR 1.574)

	SWEEP ANGLE				
AR	15°	20°	25°	30°	35°
6	X	X	X	X	X
7	X	X	X	X	X
8	X	X	X	X	X
9	X	X	X	X	X

The minimum DOC obtained for each of these design points is plotted in Figure 219. Note that when these data were generated the engine performance and weight data incorporated the nacelles with noise treatment only in the form of wall linings; the updated nacelle cost, higher technology supercritical wing and modified wing weight had not been incorporated at this time. It can be seen that for both FPR's the minimun DOC is obtained with the lowest aspect ratio and smallest amount of sweepback, and it was therefore decided to compare the wing weight equation with aspect ratio data for which correlation with actual weights were available and to run some additional design points, the results of which are presented in Figure 220 . At this time the input data were updated to include full bleed for environmental control, modified nacelle costs and a higher technology supercritical wing.

All design points incorporating FPR 1.35 engines are landing and cruise critical and it can been seen from the figure that aspect ratio 5 and 0.25c sweepback of 15 degrees provide the minimum DOC. On the other hand, the design points incorporating FPR 1.574 engines are landing and cruise critical at aspect ratio 7; and landing and approach climb gradient critical at aspect ratios of 5 and 6. The DOC's for these design points are shown by the solid lines in Figure 220 . The minimum DOC is obtained with an aspect ratio of 7 and 0.25c sweepback of 15 degrees. If the approach climb gradient requirement had not been considered, the DOC would have continued to reduce with aspect ratio as shown by the dashed lines.

Figure 221 presents ramp gross weight versus aspect ratio and sweepback for the 1.35 and 1.574 FPR airplanes. The 1.574 plot turns up at the lower aspect ratios in a

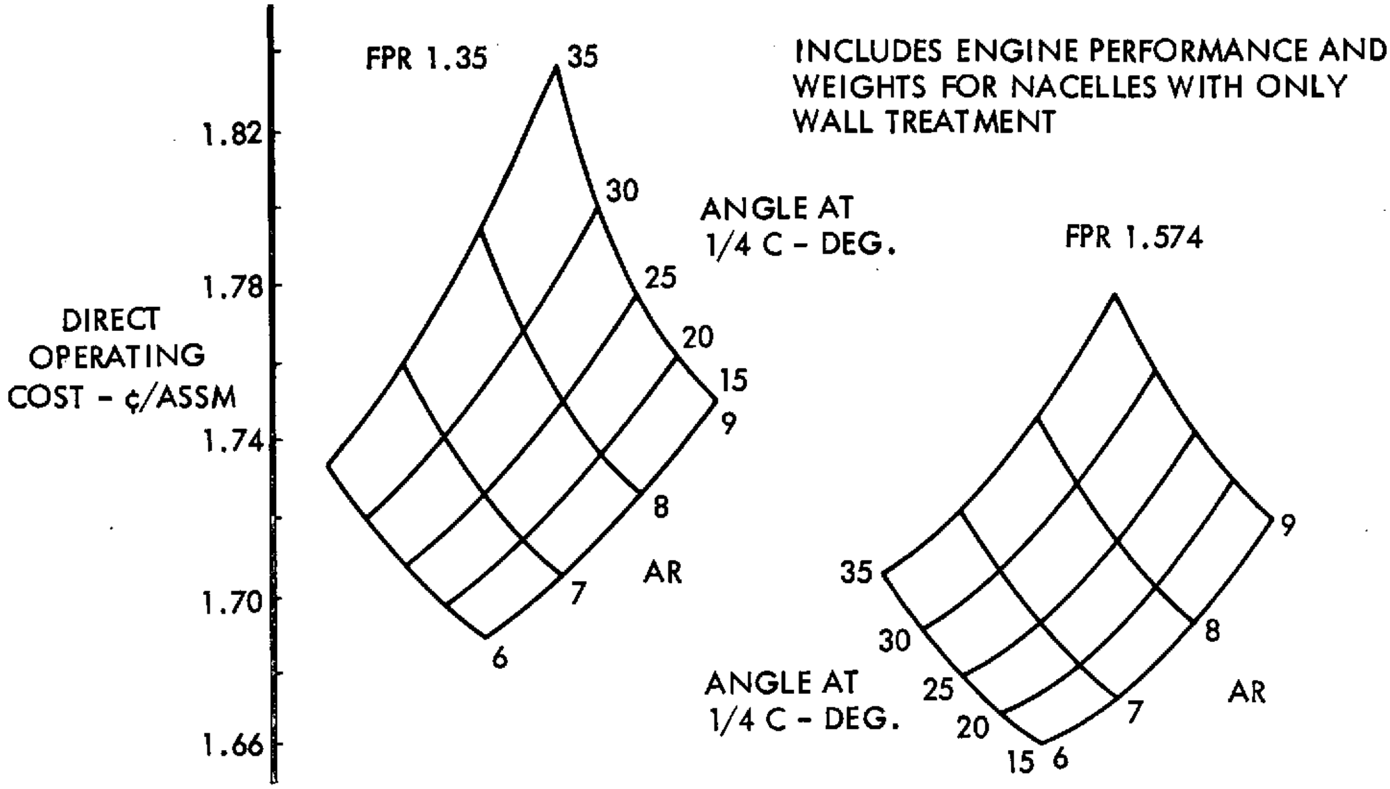


FIGURE 219: MF-DOC VS ASPECT RATIO AND SWEEP (INITIAL)

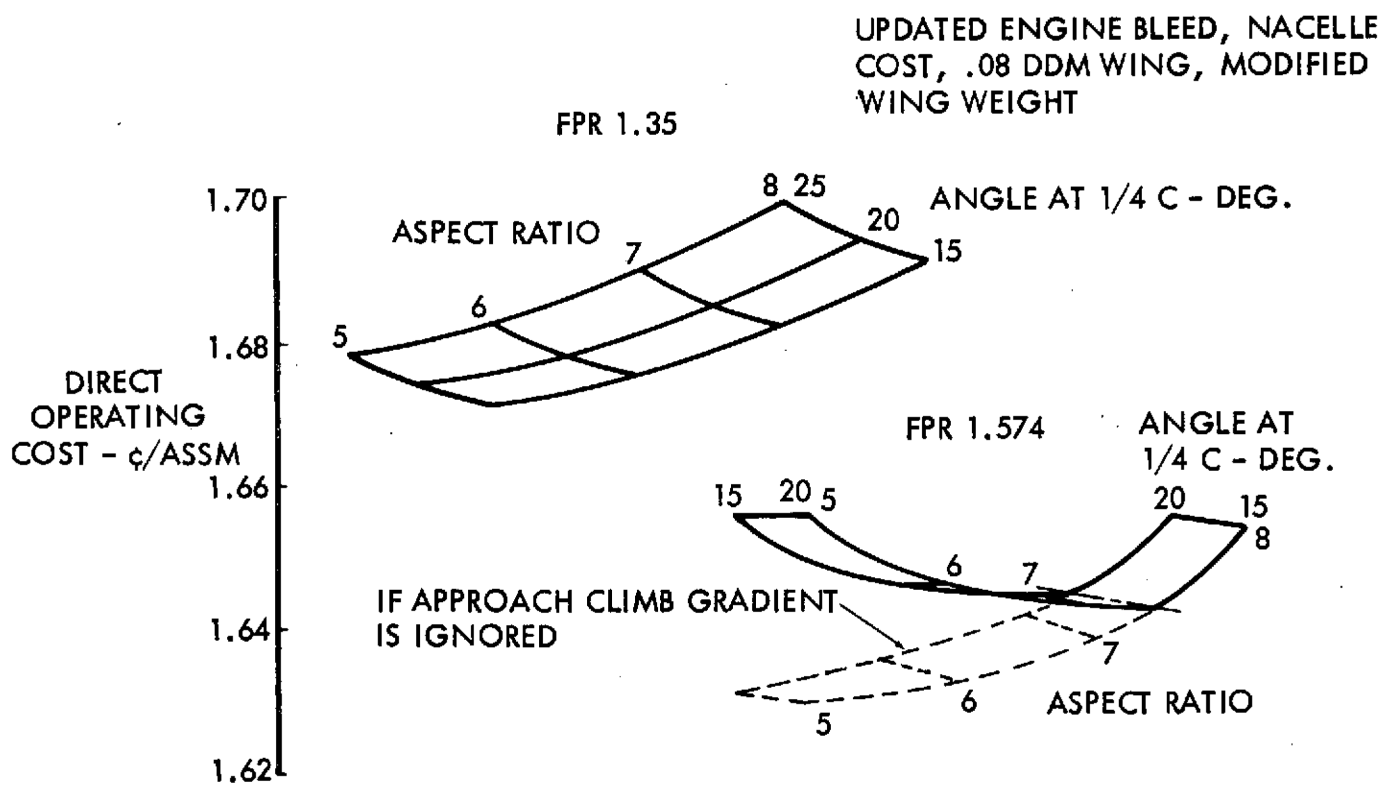


FIGURE 220: MF-DOC VS ASPECT RATIO AND SWEEP (UPDATED)

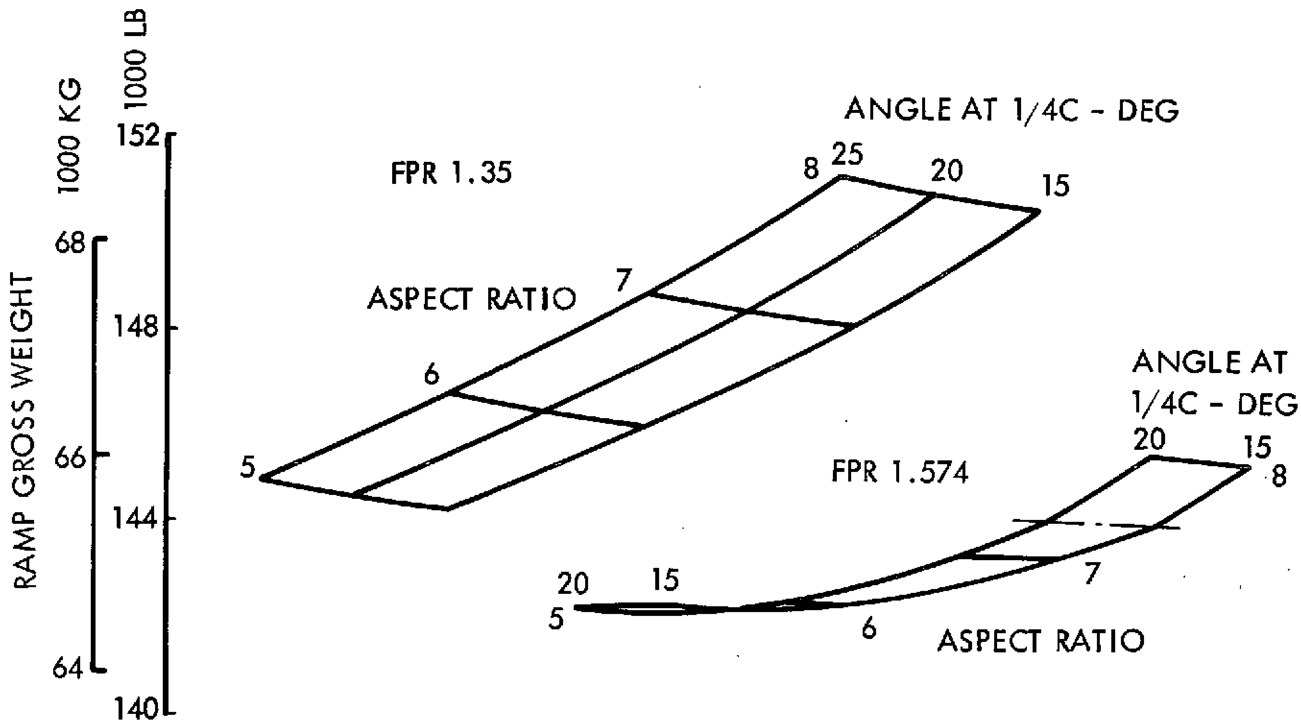


FIGURE 221 RAMP GROSS WEIGHT VS ASPECT RATIO AND SWEEP

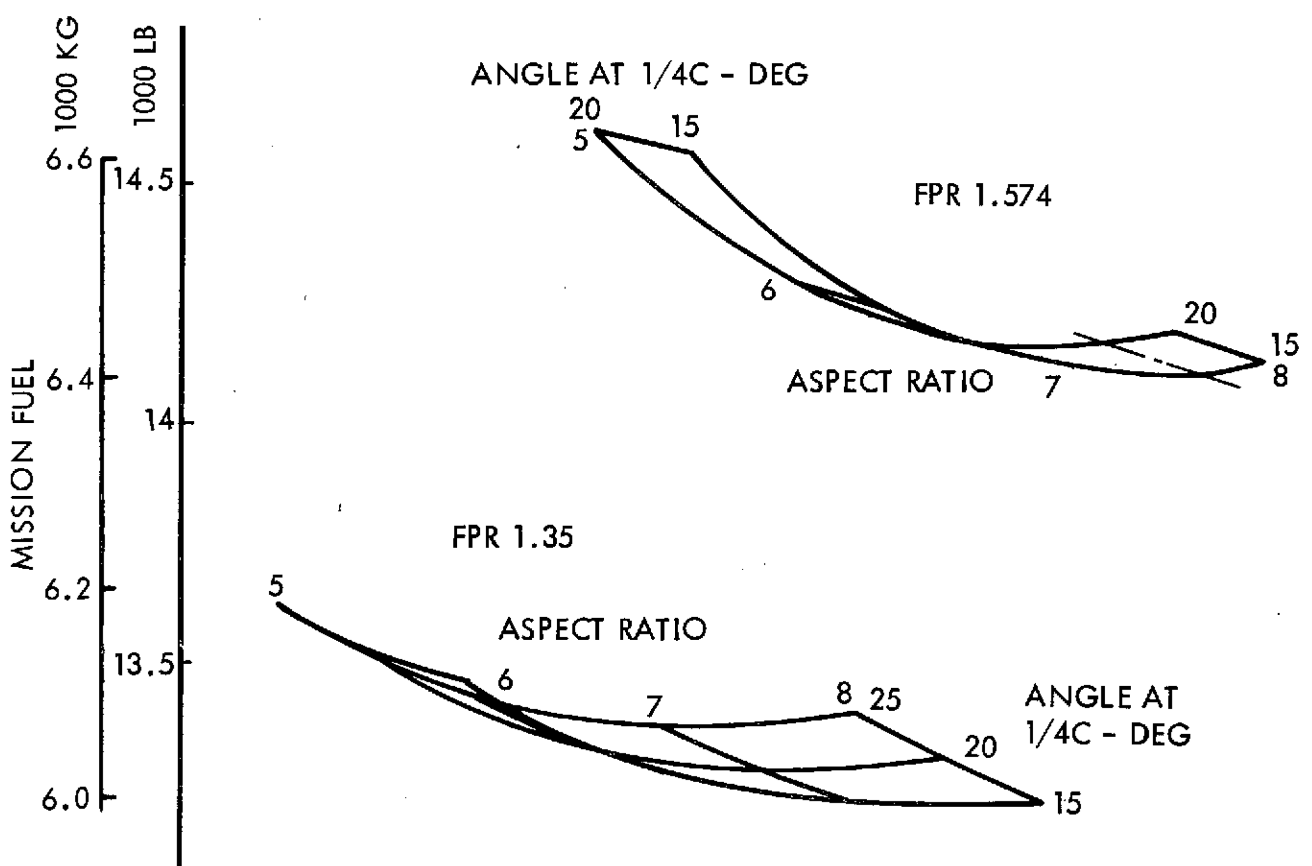


FIGURE 222 926 KM (500 N.MI.) MISSION FUEL VS ASPECT RATIO AND SWEEP similar manner to the previously discussed DOC plot because of the landing climb gradient requirement. However, in the case of ramp gross weight the optimum design point is at aspect ratio 5.5 and either 15° or 20° sweepback.

Figure 222 presents mission fuel versus aspect ratio and sweepback for the 1.35 and 1.574 FPR airplanes. The most apparent observation is that the 1.35 FPR airplanes, irrespective of aspect ratio and sweepback, use approximately 7.5 percent less fuel than the 1.574 airplanes. For both fan pressure ratios the optimum design point is between aspect ratio 7 and 8 with a sweepback of 15 degrees.

Thus the optimum design point varies dependent on the criteria considered. For the FPR 1.35 airplane, minimum DOC and RGW favor a low aspect ratio and sweep while minimum fuel favors a higher aspect ratio. For the FPR 1.574 airplane minimum RGW favors aspect ratio 5 to 6 and sweepback of 15 to 20 degrees while DOC and minimum fuel favor aspect ratio 7 to 7.5 and sweepback of 15 degrees. Fortunately, the DOC variation between aspect ratio 5 and 7 and sweepbacks of 15 and 20 degrees is less than one percent for the 1.35 FPR airplane and therefore some compromise with fuel economy can be considered. This difference in DOC becomes only about 0.5 percent if the cost of fuel is assumed to double.

Before selecting the optimum values of aspect ratio and sweepback for further vehicle development, some consideration was given to effects which the sizing programs do not include, such as gust alleviation and flutter prevention. These effects can only be determined by detailed analysis, however, experience and judgment can be used in selecting the aspect ratio and sweepback which are most likely to benefit from a gust alleviation system and probably only involve minor penalties to meet flutter requirements. The wing weight equations are based on statistical data modified to suit the STOL concepts and while not including any parameter directly associated with gust loading they do include the effect of gusts because of their statistical basis. The effect on wing weight of a gust alleviation system will be most significant on the higher aspect ratios. Consideration of flutter problems for a 0.8 Mach airplane identified that 20 degrees of sweepback is more desirable than 15 degrees.

6.4.3 Fan Pressure Ratio Trade Studies

Based on the discussion in the previous paragraphs, a twin engine arrangement, an aspect ratio of 7.0 and a 0.25c sweepback of 20 degrees have been chosen for all the baseline MF configurations. Airplanes have been sized with 1.35, 1.40, 1.50 and 1.574 FPR engines for 0.8M, 148 passengers and 914m. (3000 ft.) field length. The principal characteristics of these airplanes are presented in Table XXVII. All the configurations are very similar in size and appearance; the only feature distinguishing one from another being the size of the engines as can be seen by comparing Figures 223 and 224 .

Figures 225 and 226 show the variation of weights, thrust and costs with fan pressure ratio. The trends indicated for the range of FPR's considered are:

- o RGW and OWE decrease with increasing FPR (3.4 and 6.0%).
- o Rated thrust decreases with increasing FPR (21.5%).
- o Mission fuel weight increases with increasing FPR (6.7%).
- o DOC decreases with increasing FPR (2.4%). Doubling the cost of fuel flattens this trend to 1.2% and the DOC is almost constant for FPR's between 1.43 and 1.574.
- o Airplane and total engines price decrease with increasing FPR (3.8% and 8.1%).

6.4.4 Selected MF Baseline Vehicles

Further refinements were incorporated into the sizing program as a result of more detailed analyses. Additionally, the capability to fly 2780 Km (1500 N. Mi.) with capacity payload from a CTOL runway was incorporated. As for the OTW-IBF configurations, this operational flexibility permits an increased utilization which slightly reduces the DOC for the 926 Km (500 N.Mi.) mission. Figure 227 presents the computer sizing data for the 1.35 FPR baseline, 910m. (3000 ft.) field length vehicle optimized for DOC at 926 Km (500 N.Mi.) stage length, but with 2780 Km

148 PAX; 0.8M; 3000 FT. F.L.; 500 N.M.

* T.O. — SEA LEVEL, M = 0., 95°F

** CRUISE — 3000', M = 0.8, ISA

FPR	1.35	1.40	1.50	1.574
RGW - LB	148,379	146,407	145,121	143,278
OWE - LB	99,962	98,010	96,338	94,007
MISSION FUEL - LB	13,282	13,277	13,620	14,170
W/S - LB/SQ. FT.	58.8	58.8	58.8	58.8
INSTALLED T/W	.450	.433	.397	.368
DOC - ¢/ASSM	1.685	1.667	1.654	1.645
AIRFRAME PRICE - $M	6.0327	5.9719	5.9109	5.8044
ENGINES PRICE - $M	2.5649	2.5063	2.4202	2.3562
RATED THRUST/ENG. - LB.	36,412	34,087	30,845	28,571
INST. CRUISE SFC LB/LB/HR	0.722	0.731	0.749	0.758
INST. ENGINE T/W (T.O.*)	4.08	4.07	4.09	4.26
INST. ENGINE T/W (CRUISE**)	0.747	0.775	0.847	0.961
LAPSE RATE (0.2M)	0.761	0.770	0.791	0.813
LAPSE RATE (0.8M/30K)	0.183	0.190	0.207	0.225

TABLE XXVII: MF PRINCIPAL CHARACTERISTICS

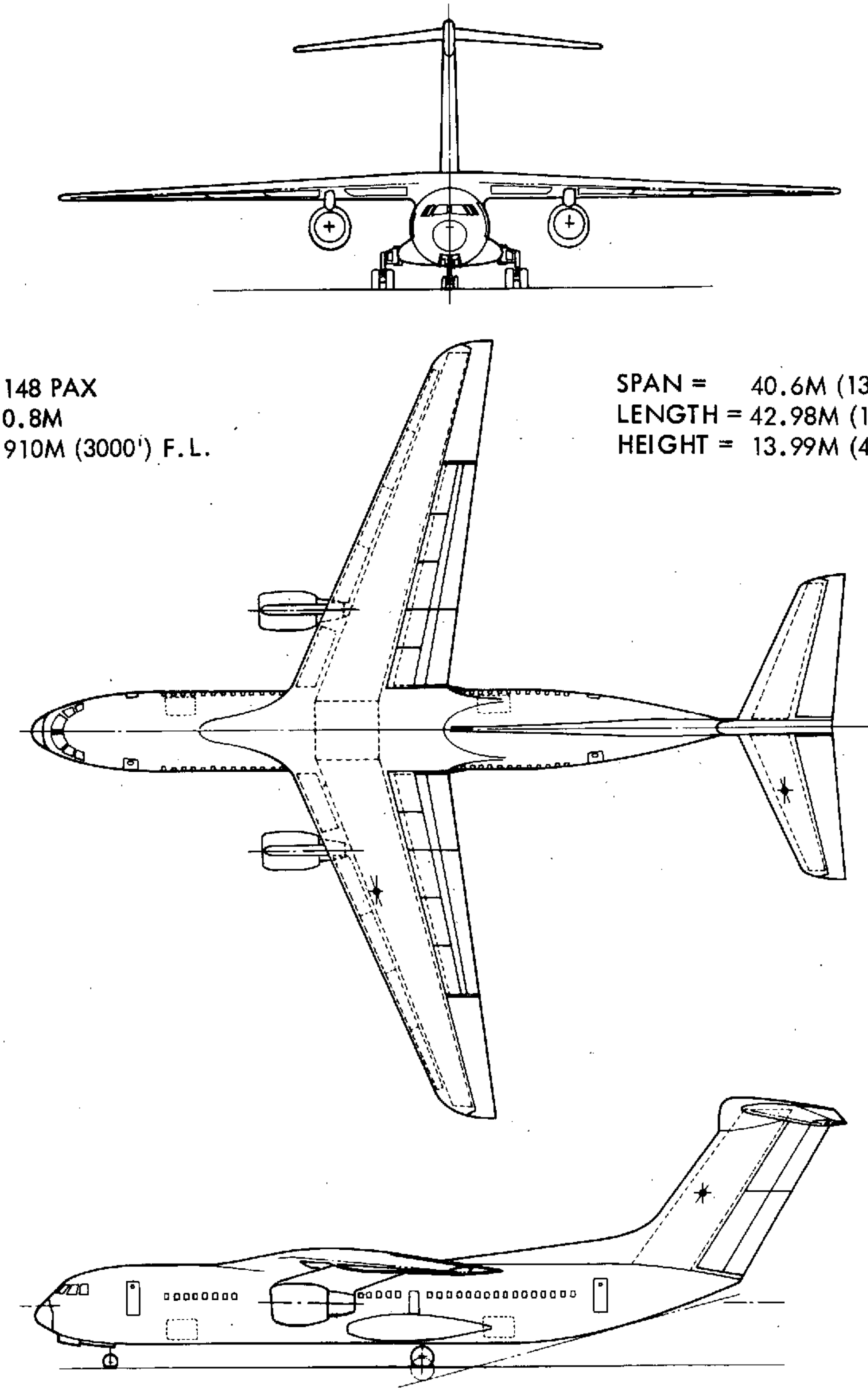


FIGURE 223 MF - GENERAL ARRANGEMENT, FPR 1.574

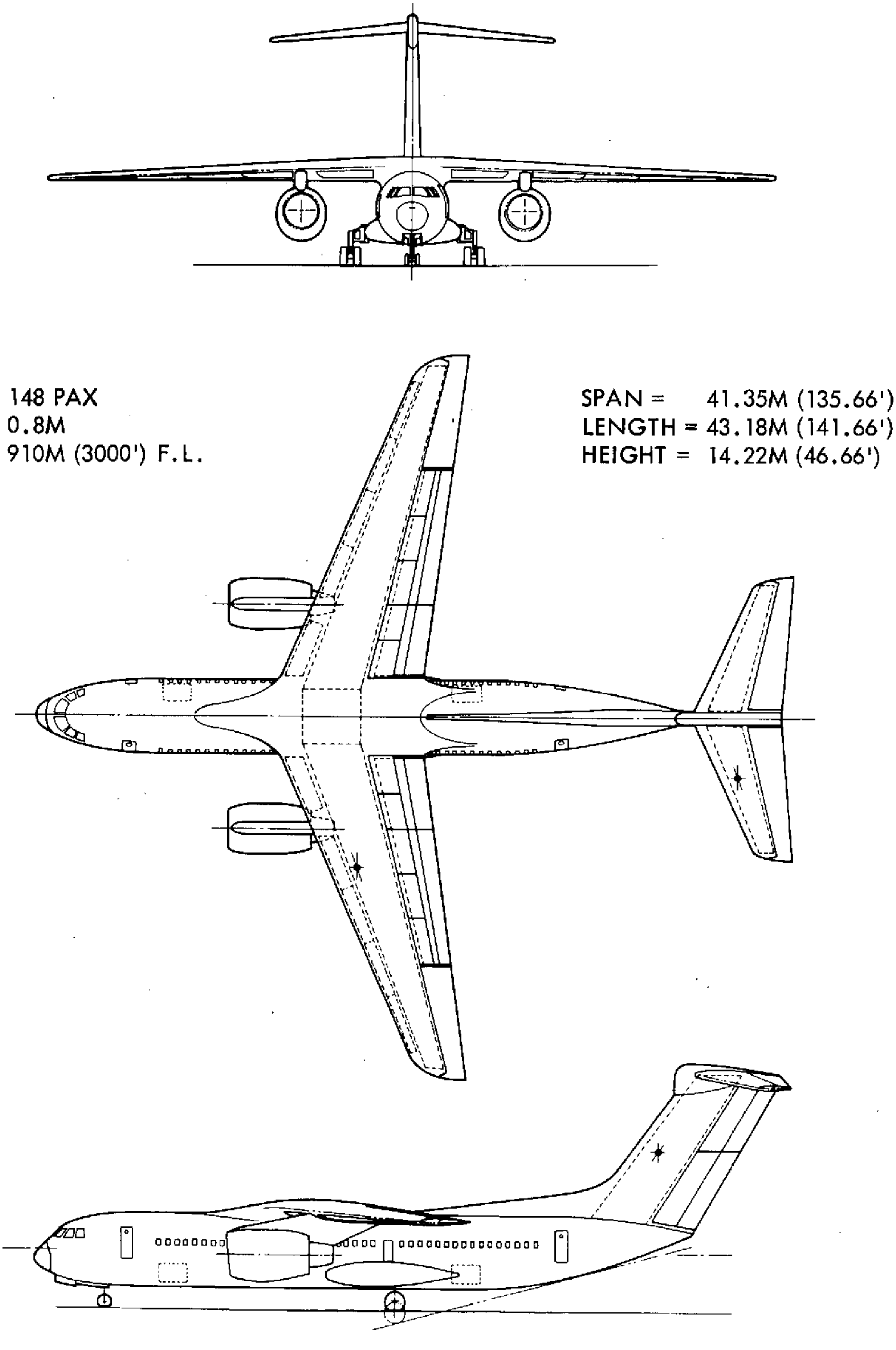
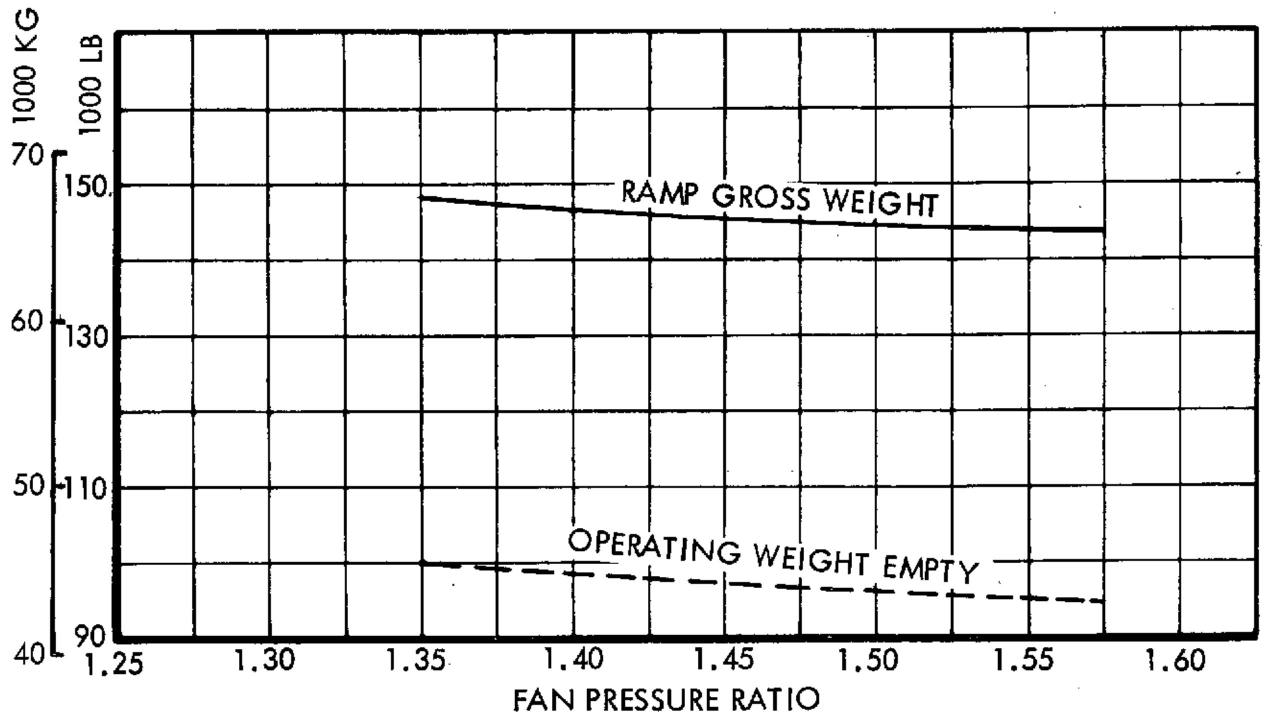


FIGURE 224 MF - GENERAL ARRANGEMENT, FPR 1.35

148 PAX; 0.8M; 910M (3000 FT.) F.L.



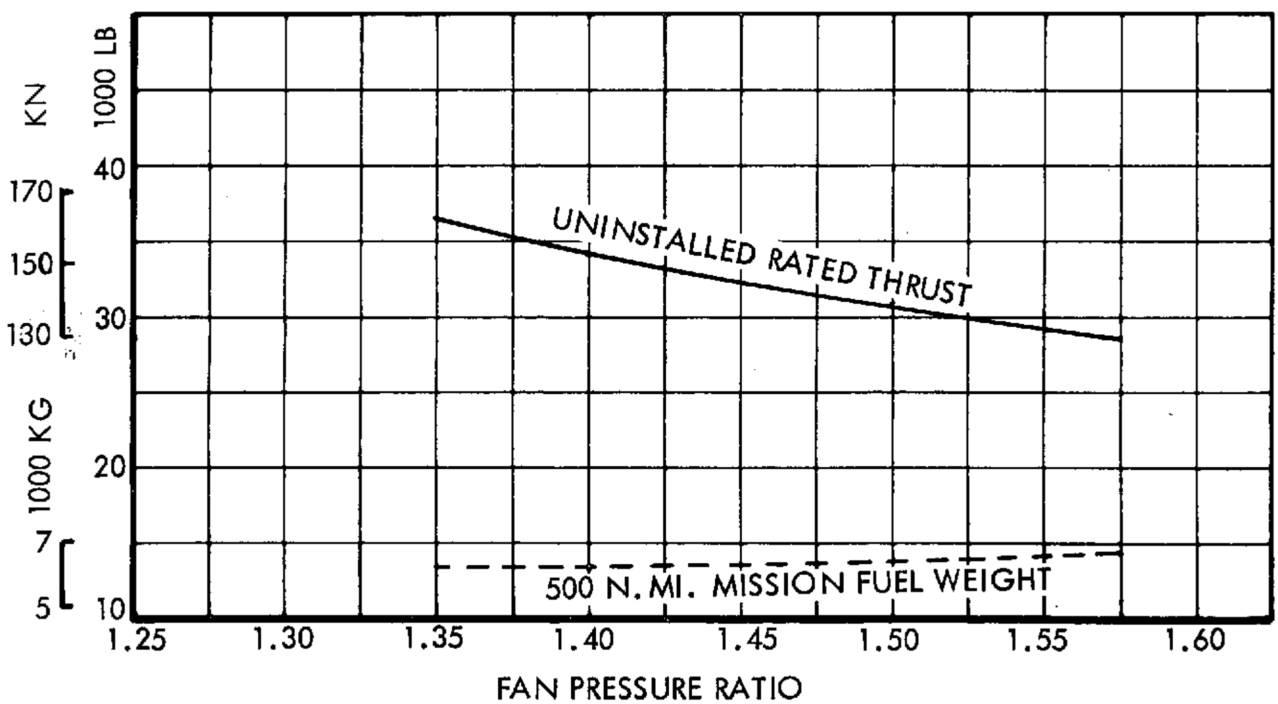
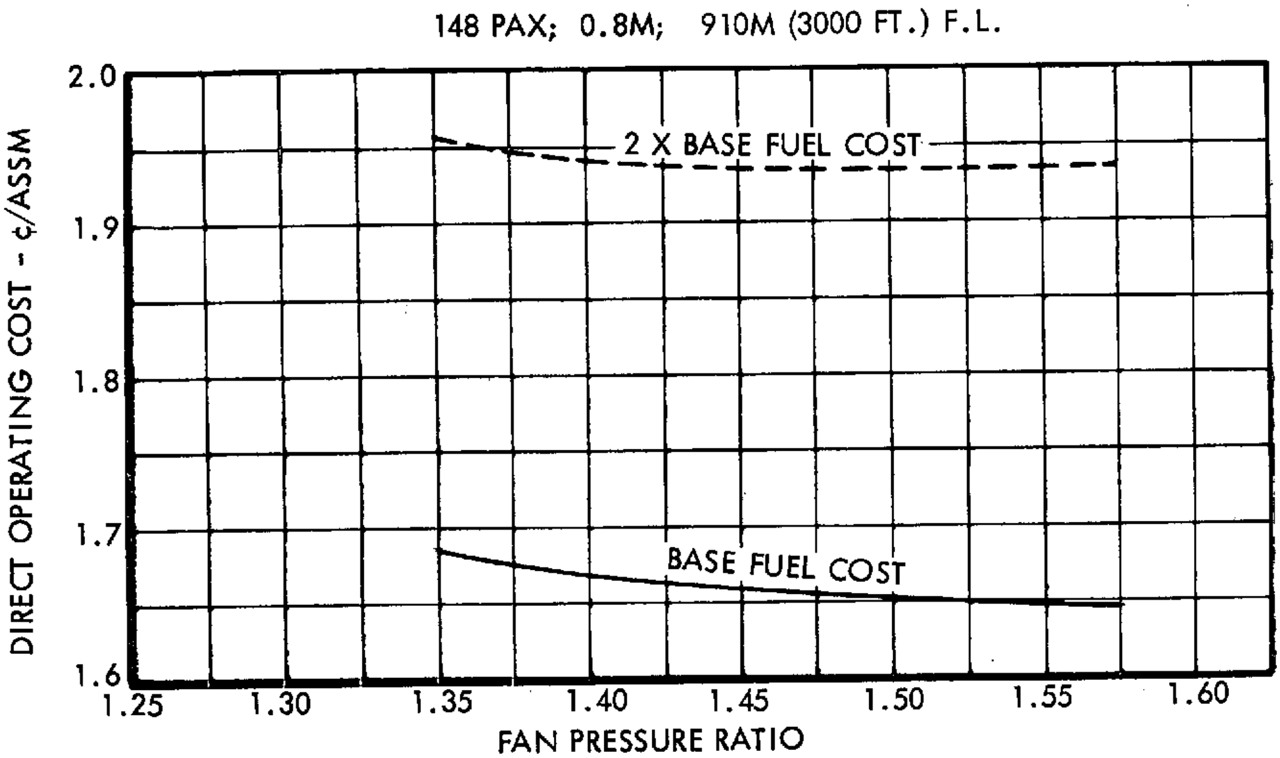


FIGURE 225 MF - AIRCRAFT WEIGHTS AND THRUST VS FPR



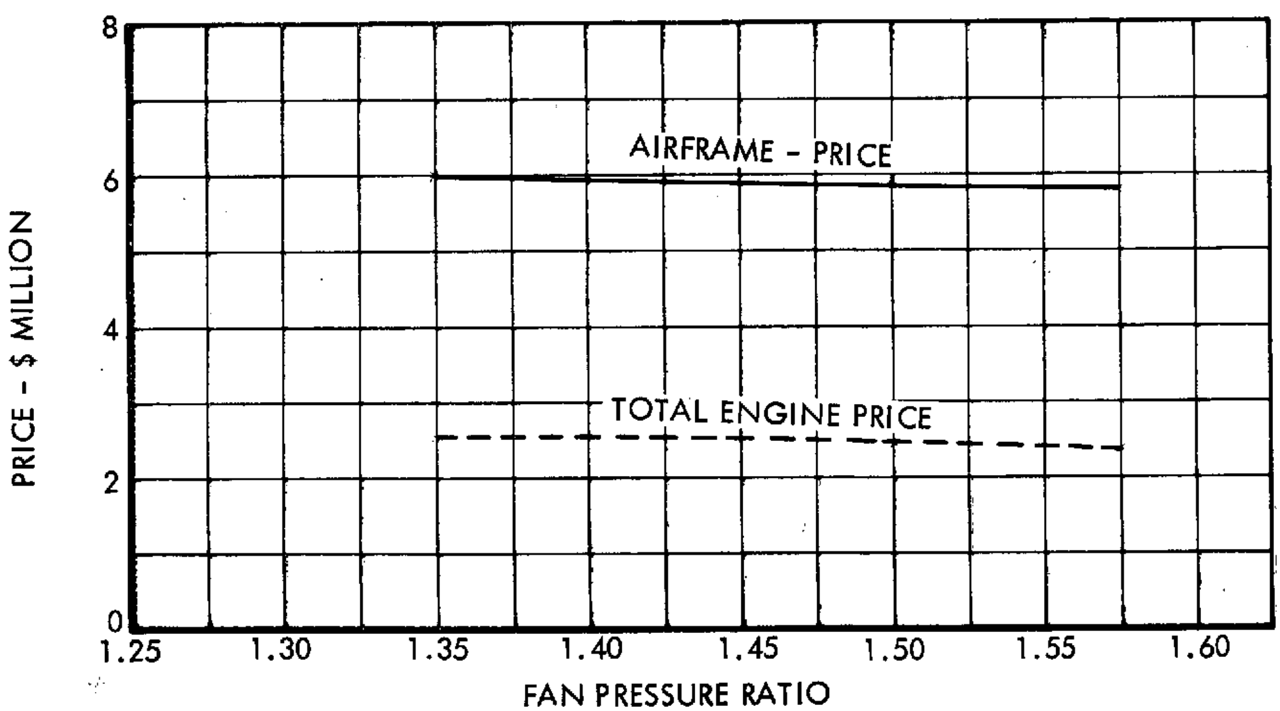


FIGURE 226 MF - DOC, AIRFRAME AND ENGINE COST VS FPR

```
 3000 FT 1.35FPR MF BASELINE 2ENG UPDATED WEIGHTS 4/18/74                      I1985=0      IVEC=0      ITR=1

STOL DISTANCE=3000.FT    MACH= .80    RANGE=1500.NM    PAYLOAD=  30340.LB    NO. OF SEATS=   148.

START CRUISE ALT=3000 .FT    SWEEP=20.0 DEG    AR= 7.00    CDC=10.    CDMISC=    .00    D M=.080

IVER=1   IMACH=4   IENG=  6  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR=1.000  SFCFAC= 1.00      ETAMAX= 1.060
NO.ENG USED INITIAL CRUISE=2.     ENG COST FACTOR= .8000     IGEAR=0     IRANGE=1     ULF= 3.750    CRUISE= 1
 WSP     S     TUN      PR   PRP  RAMPWT     W2       W3       W4       W5       OWE      CL     L/D   FVR    RESV     FUEL     VBARH
FLTIM DST23   ROC       N  T/W-R--W/S-R --ZEWR     TWTOS    TWLG5    W/S 5     TOS      TOC    DOC1 FVRCS  DOC2   DOC4      VBARV
 63.4 2611. 37893. 1.35 1.35 171877. 170970. 165000. 140318. 139075. 105212.  .226 13.10 .335   4415.   31902.     .781
 3.37 85.4  1353.    0   .400   65.5  1.000    .450     .450      58.3   26.47  14.16 1.317 .275  1.537  1.975      .095

    DRAG BUILDUP, MACH NO. =    .800
 INITIAL CRUISE LIFT COEF ICIENT=   .226
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
.00519 .00363 .00 7 .0 3 .00123 .00 99 .00057 .00064 .00100 .00050 .00     .00064 .01466 .00257 .01723
  WETTED AREA/WING AREA
WING=1.779 FUSELAGE=1.786 NACELLES= .358 PYLON= .029 H TAIL= .430 V TAIL= .383 STOT/SREF=4.765

TOCWING     SWING         AR      TAPER      FUS LEN   FUS SWET  THRUST     SHOR       SVERT      DNAC      TRVERT
  .1416    2611.42       7.00         .30    136.25    4661.38  37893.69    553.62     492.77      9.38        .00

    W NG           WHOR           WVER           WFUS            WLG            WHYD           WSC            WPP
   2 690.67       3 95.31        3425.10        2 79.81         7218.82        1015.25        3045.74       15385.27
  WELEC          WAPU           WINSTR            WAV            WAC             WAI           WFUR            DUCTW
    1953.14       1 09.38         700.00         1250.00        2437.06          751.52       10656.00           .00
   WNAC          WPYL            WOPIT          WEMTY             OW             ZFW            AMPR             GW
    2645.23       2612.21        2641.91       102570.50      105212.41      135 2.41        88378.97      171869.63
  SWING            AR           SWEEP           WGRSS          WFUEL           PAYLD          THRUST          TAPER-
    2610.42         7.00           16.02       171876.70       36317.21       30340.00       37897.91           .30
  TCRO T        TCTIP            SHOR           SVERT          FLENGTH         FUSAREA        DELPRESS        VDIVE
     15.01          1 .47         5 3.62          492.77         136.25         4661.38           8.80         408.86
 RANGE/D.O.C. DAT
   RANGE      DOC1      DOC2      DOC4      DOC10
    500.     1.735     2.034     2.634     4.432

TOTAL COST OF
A/C LES  ENG  TOTAL ENG  COMPLETE A/C      FUEL500
   654787 .     208 2 .        862869 .       14536.
DOLLARS PER NAUTICAL MILE COST OF:
  CREW       FUEL       INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
     .569       .513       .195       .136       .09        .062        .160        .320       .925      2.956
   1500.      1.317      1.537      1.975      3.291
    400.      1.8        2.215      2.869      4.830
    300.      2.143      2.510      3.258      5.487
    200.      2.653      3.112      4.032      6.789

 63.4 2610. 37898. 1.35 1.35 171877. 170970. 165000. 140318. 139075. 105212.  .226 13.10 .335   4415.  31902.     .781
 3.37 85.4  1353.    0   .400   65.5  1.00      .450     .450      58.8   26.47  14.16 1.317 .275  1.537  1.975      .095
   1.00       1.0       1.0       1.0        1.0        1.0
   1.0        1.0       1.0       1.0        1.0        1.00
   1.0        1.0       1.0       1.0        1.0        1.00
DOVRS 0      FPOF 1      FPUF 0       ERMD 0
 *     TASK UNITS=1       AC UM T L=7      CORE=19 68     CORE SEC=178     ACCUM CPU=194     ****
```

FIGURE 227   COMPUTER SIZING DATA: 2-ENGINE MF @ 1.35 FPR, 910M (3000 FT.) FIELD

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(1500 N.Mi.) RTOL capability. Similar data are provided for the 1.35 FPR, 1070m. (3500 ft.) and 1220m. (4000 ft.) vehicles and the 1.47 FPR, 1220m. (4000 ft.) vehicle in Figures 228 through 230.

6.5 MF FUEL CONSERVATIVE VEHICLES

To determine the optimum MF vehicles on the basis of minimum fuel consumption or minimum DOC at inflated fuel prices it was necessary to reoptimize both vehicle configuration and mission parameters. Although the minimum DOC airplanes which have been optimized for 1972 fuel prices and the baseline mission are 2-engine configurations as described in Section 6.4, it was expected that the minimum fuel configurations would have a four engine arrangement. Initial emphasis was therefore placed on this arrangement. Later in the study, importance was attached to cost-optimization at a range of inflated fuel prices and it was then necessary to consider both 2- and 4-engine arrangements. Fuel conservative MF airplanes have therefore been sized for combinations of field length, cruise speed and altitude, aspect ratio and fan pressure ratio. For each of these design points, a range of cruise power settings was examined to determine the power setting providing the least fuel consumption.

6.5.1 FPR 1.35 Configurations

Both two-engined and four-engined configurations have been sized and analyzed at this FPR. Because low fan-pressure-ratio engines have large diameters at the high thrust levels required by the 2-engined arrangement, it was necessary to locate the wing above the fuselage to provide adequate clearance between the engines and the ground. The 4-engined configurations have smaller diameter engines and can be arranged to have acceptable engine to ground clearance with the more desirable low-wing configuration. A sizing comparison of high and low wing airplanes indicated that at 1220 m. (4000 ft.) field length and 0.8 M cruise the low wing has an advantage of 0.3% in fuel consumption and DOC, in addition to the advantages of passenger appeal and greater safety. Data similar to that previously described in Section 4.5.1 were generated by the computer sizing program/machine plotter for each design point.

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```
 35  FT 1.35FPR MF BASELINE 2ENG UPDATED WEIGHTS 4/18/74                 I1985=0      IVEC=0      ITR=1

STOL DISTANCE=3500.FT   MACH= .80    RANGE=1500.NM    PAYLOAD=  30340.LB    NO. OF SEATS=   148.

START CRUISE ALT=30   .FT    SWEEP=20.0DEG    AR= 8.0    CDC=10.    CDMISC=    .00    DOM=.080

IVER=1    IMACH=4    IENG=  6   VBARH=VARIABLE   VBARV=VARIABLE   ETAPWR=1.00   SFCFAC= 1.00      ETAMAX= 1.061
NO.ENG USED INITIAL CRUISE=2.     ENG COST FACTOR= .800      IGFAR=0      IRANGE=1      ULF= 3.750     CRUISE= 1
 WSP     S      TUN      PR   PRP  RAMPWT     W2        W3        W4       W5        OWE       CL     L/D   FVR     RESV      FUEL      VBARH
FLTIM DST23   ROC       N   T/W R  W/S R    ZFWR      TWTO5     TWLG5    W/S 5      TOS      TOC    DOC1 FVRCS   DOC2    DOC4       VBARV
 75.4 194 .  314 .  1.35 1.35 152753. 152013.  146924.  126125.  125842.   91784.   .268 14.03 .492    3708.   26911.       .736
 3. 7 98.5   1 96.    0    .37    78.0  1.0       .416      .416       70.6    29.38   13.69 1.216 .398  1.402   1.772       .086

     DRAG BUILDUP, MACH NO. =     .80
 INITIAL CRUISE LIFT COEFFICIENT=     .268
CDWING  CDFUS  CDPYL   CDNAI   CDHOR   CDVER   CDPOD CDRUF  CDCOMP   CDTRM   CDMISC CDINT    CDO     CDI   CDTOT
.0 516 .0 48   8 .  3   .   98 .  .86 .  76 .  7.  .  1   .   5  .          . 7  .01594 .0 318 .01913
  WETTED AREA/WING AREA
WING=1.754 FUSELAGE=2.392 NACELLES= .397 PYLON= .032 H TAIL= .328 V TAIL= .321 STOT/SREF=5.225

TOCWING     SWING          AR      TAPER      FUS LEN    FUS SWET   THRUST    SHOR        SVERT        DNAC      TRVERT
   .1369    1048.59        8.0           .30     136.25    46 1.38  3139 .70     314.82      308.43        8.54         .0

    WING             WHOR           WVER           WFUS              WLG            WHYD             WSC             WP
    1762 .4        1931 .76        2143.79        21856.            6415.62            93 .21         2817.62         126 1.54
   WEL C           WAPU           WINSTR           WAV              WAC             WAI             WFUR            DUCTW
     18 9.27        1 74.96          70  .          1251 .           2437.66            702.07         10650.                .0
   WNAC            WPYL            WOPIT          WEMTY              OW              ZFW             AMPR              GW
     2183.52        216 .32         2453.41        893  .85          91784.26        12   4.26        77476.47         152743.56
   SWING            AR            SWE P           WGRS              WFUEL           PAYLD           THRUST           TAPER
     1048.5          8.0            16.52         152752.85          30619.31         30340.          3140 .93             .30
   TCRO T         TCTIP          SHOR             SVERT             FLENGTH          FUSAREA         DELPRESS          VDIVE
       14.5          1 .09          314.82          308.43            136.25          46 1.38            8.30           408.56
 RANGE/D.O.C  DAT
   RANGE       DOC1       DOC2        DOC4       DOC10
    50  .       1.602      1.857      2.369      3.913

TOTAL COST  F
A/C LES   NG  TOTAL ENG  COMPLET  A/C      FUEL5
   6 27 8  .     198327 .      7935  8.       1240 .
DOC ARS PER NAUTICAL MILE COST OF:
  CREW       FUEL       INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
    .  7       .83        .181       .305       .191         .15         .150       .287      .85       2.729
   15  .       1.2         1.412      1.7 2      2.8 2
   10  .       1.71        2.0        2.584      3.263
   50  .       1.980       2.3        2.93       4.857
   20  .       2.0         2.55       3.687      5.037

 75.4 19   .  3  1 .  1.35  1.35 152753. 152 3. 146924. 126  . 125842.  91784.   .268 14.03 .492   3708.  26911.      .736
 3. 7 98.5   1 9 .    0    .37    78.0   1.0        .416      .416      70.6    29.38  13.69 1.216 .398  1.402  1.772      .086
   1.0          1.           1.          1.          1.         1.1
   1.0          1.           1.          1.          3.         3.0
   1.0          1.0          1.          1.          1.         1.0
      ER             ERO           ERO           ERMD
 **    TASK UNITS=1        AC  MTL=75       CORE=19 68     CORE S C=137      AC UM CPU=189     ****
```

FIGURE 228   COMPUTER SIZING DATA: 2-ENGINE MF @ 1.35 FPR, 1070M (3500 FT.) FIELD

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40  FT 1.35FPR MF BASELINE 2ENG UPDATED WEIGHTS 4/18/74                I1985=0      IVEC=0      ITR=1

STOL DISTANCE=40  .FT   MACH= .80   RANGE=150 .NM   PAYLOAD= 3034 .LB   NO. OF SEATS=  148.

START CRUISE ALT=30   .FT   SWEEP=20. DEG   AR=10.    CDC=10.   CDMISC=  .0    DIM=.L8

IVER=1   IMACH=4   IENG=  6  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR=1.0    SFCFAC= 1.0       ETAMAX= 1.06
NO.ENG USED INITIAL CRUISE=2.    ENG COST FACTOR= .80      IGEAR=0     IRANGE=1    ULF= 3.750    CRUISE= 1
 WSP    S    TUN    PR  PRP  RAMPWT    W2       W3      W4      W5     OWE    CL    L/D  FVR   RFSV   FUEL   VBARH
FLTIM DST23  ROC    N  T/W R  W/S R   ZFWR    TWTO5   TWLG5   W/S 5   TOS    TOC   DOC1 FVRCS DOC2  DOC4   VBARV
 87.6 1593. 27826. 1.35 1.35 145020. 146354. 139539. 12  02. 121850.  8714 .  .312 15.04 .697   3 25.  24170.   .723
 3.58105.4  1  8.   0   .351   90.6  1.0     .386    .386     82.5   31.84  13.    .69 .56  1.3 5  1.6 8      .081

    DRAG BUILDUP, MACH NO. =   .800
 INITIAL CRUISE LIFT COEFFICIENT=   .312
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUF  CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
.00529 .00595 .00  9 .0  36 .0  81 .0  83 .0  93 .0  76 .0 1.   .0  5. .0        .  76 .01730 .0 34  .02 73
  WETTED AREA/WING AREA
WING=1.75  FUSELAGE=2.926 NACELLES= .431 PYLON= .035 H TAIL= .260 V TAIL= .304 STOT/SREF=5.71

TOCWING    SWING         AR      TAPER      FUS LEN   FUS WET  THRUST    SHOR       SVERT      DNAC      TRVERT
  .13     1592.91       10.0          .30    136.25   46 1.38  27326.37   204.27     238.63       8.04        .0

                  WHOR           WVER            WFUS             WLG            WHYD            WSC             WP
   16 73.  4       125 .79         1658.97         2169 .2          6091.85          917.5          27  .65        11 07.95
  WFL C           WAPU          WINSTR            WAV             WAC             WAI            WFUR           DUCTW
    1765.14        1061.14          71  .0           1250.0         2437.06          671.09         1065 .0             .0
   WNAC           WPYL           WOPIT           WEMTY             OW             ZFW            AMPR             GW
    1930.25        1912.06         2351.0          84792. 5        87143.95        1 7483.95       74138. 5        14 97 .56
  SWING             AR          SWE P           WGRS             WFUEL           PAYLD           THRUST          TAPER
    1592.              10.0           17.23        1450  .16        27495.61         30 40 .         27825.90             .30
  TCRO T          TCTIP          SHOR           SVERT            FLENGTH          FUSAREA         DELPRES          VDIVE
      13.80          16.62          204. 7          238.63           136.25          46 1.38            8.             40 .
 RANGE/D.O C  DAT
   RANGE       DOC1       DOC2       DOC4       DOC10
    50 .      1.542      1.7 3      2. 36      3. 24

TOTAL COST
A/C LESS     TOTAL ENG   COMPLETE A/C     FUEL50
   5811924.     1 675 0.      76 849 .       1 2  .
DOL ARS PER NAUTICAL MILE COST OF:
 CREW       FUEL       INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL  MTNCE BURDEN DEPRECIATION TOTAL
     .          .394        .175        .10         .1 3          .151        .14         .274        .830     2.6 7
   150 .           9        1.3 5       1.6 8       2.  5
    40 .                    1. 3        2.4 1       3.965
    30 .       1.           2. 9        2.78        4.52
    20 .        .367        2.731        .4         5. 4

 87.  1593. 27      1.35 1.35 14    14 3            12          8         714 .   .312         697                          .7
  3. 8105.4                 .351                                          82.5      1. 4  13.
```

FIGURE 229 COMPUTER SIZING DATA: 2-ENGINE MF @ 1.35 FPR, 1220M (4000 FT.) FIELD

```
BASE 1500M 147FPR MF 4/18/74 NF0147SFCNB/03CRMF                              I1985=0     IVEC=0     ITR=1

STOL DISTANCE=4000.FT   MACH= .80   RANGE=1500.NM   PAYLOAD= 30340.LB   NO. OF SEATS=  148.

START CRUISE ALT=30000.FT   SWEEP=20.0DEG   AR=10.00   CDC=10.   CDMISC=  .00   DUM=.080

IVER=1   IMACH=4   IENG= 53  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .820  SFCFAC= 1.070   ETAMAX= 1.070
NO.ENG USED INITIAL CRUISE=2.     ENG COST FACTOR= .8000     IGEAR=0     IRANGE=1     ULF= 3.750    CRUISE= 1
 WSP    S     TUN    PR  PRPP RAMPWT    W2       W3       W4      W5      OWE     CL    L/D   FVR    RESV    FUEL    VBARH
FLTIM DST23  ROC     N  T/W R  W/S R   ZFWR    TWTO5    TWLG5    W/S 5    TOS     TOC   DOC1 FVRCS  DOC2   DOC4    VBARV
 89.0 1630. 25830. 1.47 1.47 150121. 149206. 145102. 123031. 120875.  83745.  .317 15.44 .759   3755.  27246.   .704
 3.31 52.6  2387.   0   .319   91.5  1.000    .354     .354     82.5   29.24  13.07 1.155 .617  1.343  1.717    .080

   DRAG BUILDUP, MACH NO. =    .8000
 INITIAL CRUISE LIFT COEFFICIENT=    .317
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI   CDTOT
.00529 .00581 .00006 .00026 .00080 .00083 .00091 .00075 .00100 .00050 .00000 .00075 .01697 .00355 .02052
  WETTED AREA/WING AREA
WING=1.758 FUSELAGE=2.859 NACELLES= .271 PYLON= .024 H TAIL= .256 V TAIL= .306 STOT/SREF=5.474

TOCWING    SWING        AR      TAPER     FUS LEN   FUS SWET  THRUST     SHOR      SVERT      DNAC     TRVERT
  .1307   1630.36      10.00       .30    136.25   4601.38  25828.94    205.96    245.63      7.18      .00

  WWNG          WHOR          WVER          WFUS           WLG           WHYD          WSC           WPP
  17436.15      1263.13       1707.28       21783.27       6305.07       928.49        2785.48       11736.71
 WELEC         WAPU          WINSTR         WAV           WAC           WAI           WFUR          DUCTW
  1800.85       1070.22       700.00        1250.00       2437.06       673.80        10656.00      .00
 WNAC          WPYL          WOPIT         WEMTY          OW            ZFW           AMPR          GW
  1834.77       1948.10       2428.54       86316.45       83744.98      119084.98     74657.42      150085.48
 SWING          AR           SWEEP         WGRSS          WFUEL         PAYLD         THRUST        TAPER
  1630.36       10.00         17.23        150120.72      31000.50      30340.00      25829.91       .30
 TCROOT        TCTIP         SHOR          SVERT         FLENGTH       FUSAREA       DELPRESS      VDIVE
    13.85       10.59        205.96         245.63        136.25        4601.38        8.30         408.86
 RANGE/D.O.C. DATA
   RANGE     DOC1      DOC2      DOC4      DOC10
    500.     1.490     1.748     2.264     3.812

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C     FUEL500
  5920605.     1651956.     7572560.       12514.
DOLLARS PER NAUTICAL MILE COST OF:
 CREW      FUEL      INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MINCE BURDN DEPRECIATION TOTAL
  .540      .440       .164      .090      .08      .047      .123      .264       .774      2.539
  1500.    1.155      1.343     1.717     2.841
  400.     1.612      1.895     2.459     4.152
  300.     1.817      2.139     2.782     4.712
  200.     2.225      2.625     3.424     5.824

 89.0 1630. 25830. 1.47 1.47 150121. 149206. 145102. 123201. 120875.  83745.  .317 15.4  .759   3755.  27246.   .704
 3.31 52.6  2387.   0   .319   91.5  1.000    .354     .354     82.5   29.24  13.07 1.155 .617  1.343  1.717    .080
   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
DOVRS 000000 FPOF 000000 FPUF 000000 ERMD 000000
 ***** TASK UNITS=1        ACCUM TTL=49      CORE=19068     CORE SEC=173     ACCUM CPU=135     **
RED.U T.D
ED 11E-04/18/74-16:32:57.
```

FIGURE 230 COMPUTER SIZING DATA: 2-ENGINE MF @ 1.47 FPR, 1220M (4000 FT.) FIELD

An examination and comparison of these data indicates that 'least fuel' vehicles are distinguished by the following characteristics:

- Absolute minimum mission fuel is achieved by the 4-engined configuration at the lowest Mach number (0.55 M) and longest field length (1830 m.; 6000 ft.). This airplane has an aspect ratio of 14 and a design cruise altitude of 7320 m. (24,000 ft.).

- For 1830m. (6000 ft.) and 1220m. (4000 ft.) field lengths, aspect ratio 14 is required at all Mach numbers up to and including 0.8 M to achieve minimum fuel consumption. For 910 m. (3000 ft.) field length the optimum aspect ratio reduces gradually from 14 at 0.55 M to 7 at 0.8 M.

- Cruise altitude for minimum fuel, increases with decreasing field length, being 7320 m. (24,000 ft.) for 1830 m. (6000 ft.) field length increasing to 9140 m. (30,000 ft.) at 914 m. (3000 ft.). Increase in cruise Mach number results in the optimum cruise altitude increasing to 9750 m. (32,000 ft.) at 1830 m. (6000 ft.) and 10,970 m. (36,000 ft.) at 914 m. (3000 ft.) for 0.8 M.

In contrast with the above, the 'least cost' vehicles are characterized as follows:

- The absolute minimum DOC at 1972 fuel price is achieved by the 2-engined configuration at the highest Mach number (0.8 M), the longest field length, 1830 m. (6000 ft.), the lowest altitude and an aspect ratio of 10.

- Shortening the field length to 1220 m. (4000 ft.) requires the same Mach number and aspect ratio but increases the cruise altitude to 9130 m. (30,000 ft.).

- Shortening the field length further to 914 m. (3000 ft.) results in a reduction in Mach number to 0.75 M, aspect ratio to 7 and cruise altitude to 8840 m. (28,000 ft.).

Conclusions of a similar nature were determined for the interaction between the various parameters at different fuel prices.

From these basic data the following figures and discussions have been prepared:

- Figure 231 presents mission fuel versus design cruise Mach number for field lengths of 910 m., 1220 m. and 1830 m. (3000, 4000 and 6000 ft.). The solid lines indicate the airplanes which have been configured to use the least fuel while the dashed lines indicate designs which have been configured for least DOC at 23¢/gallon. At all field lengths the minimum mission fuel corresponds to a speed of 0.6 M or lower.

- Figure 232 shows similar data for the 2-engine arrangement. Comparison of the 2- and 4-engine data shows the 4-engine vehicles to have slightly superior fuel consumption at 910 m. (3000 feet) as minimum fuel configurations but noticeably inferior consumption at 0.75 M and above when optimized for DOC at 23¢/gallon. At 1220 m. and 1830 m. (4000 and 6000 ft.) the 4-engine configurations have superior consumption at all Mach numbers.

- Figures 233 and 234 present DOC at 23¢/gallon versus Mach number for both 2- and 4-engine arrangements. Comparing the figures indicates that the 2-engine arrangement provides lower DOC at all Mach numbers and field lengths. It should also be noted that the 2-engine vehicles have higher optimum Mach numbers than their 4-engine counterparts.

- Figures 235 , 236 and 237 show DOC at fuel prices of 11.5¢, 23¢, 46¢ and $1.15 per gallon versus Mach number for field lengths of 910 m., 1220 m., and 1830 m. (3000, 4000 and 6000 ft.) and both 2- and 4-engine arrangements. In all cases the 2-engine airplanes have lower DOC's than the 4-engine vehicles. The optimum Mach numbers (for minimum DOC) decrease with fuel cost as shown by the chain-dot lines. Note that the optimum Mach number increases with increasing field length and that in all cases the 2-engine arrangement optimizes at a higher Mach number than the 4-engine arrangement.

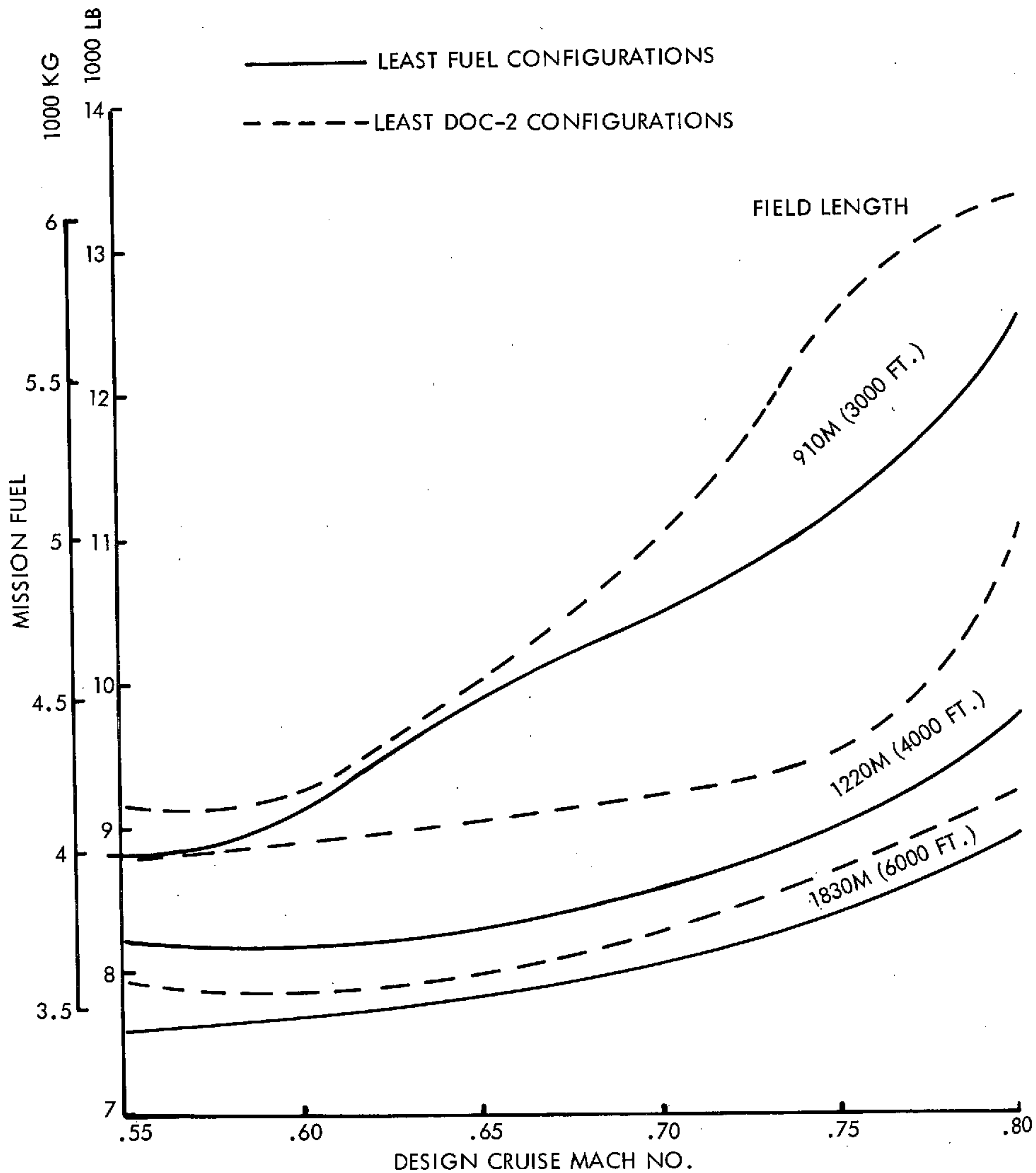

FIGURE 231 1.35 FPR MF: MISSION FUEL VS CRUISE MACH NO.: 4-ENGINES

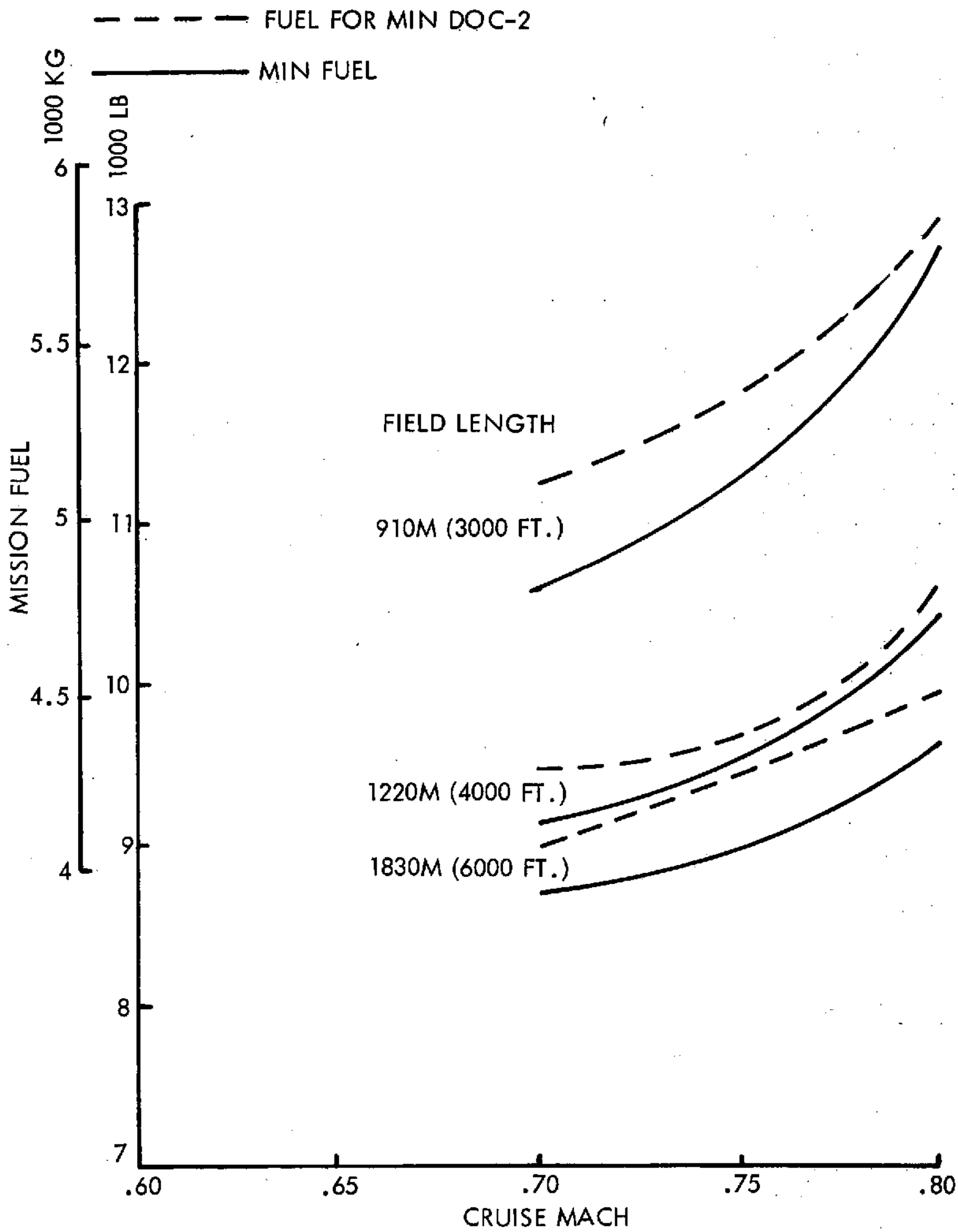

FIGURE 232 1.35 FPR MF: MISSION FUEL VS CRUISE MACH: 2-ENGINES

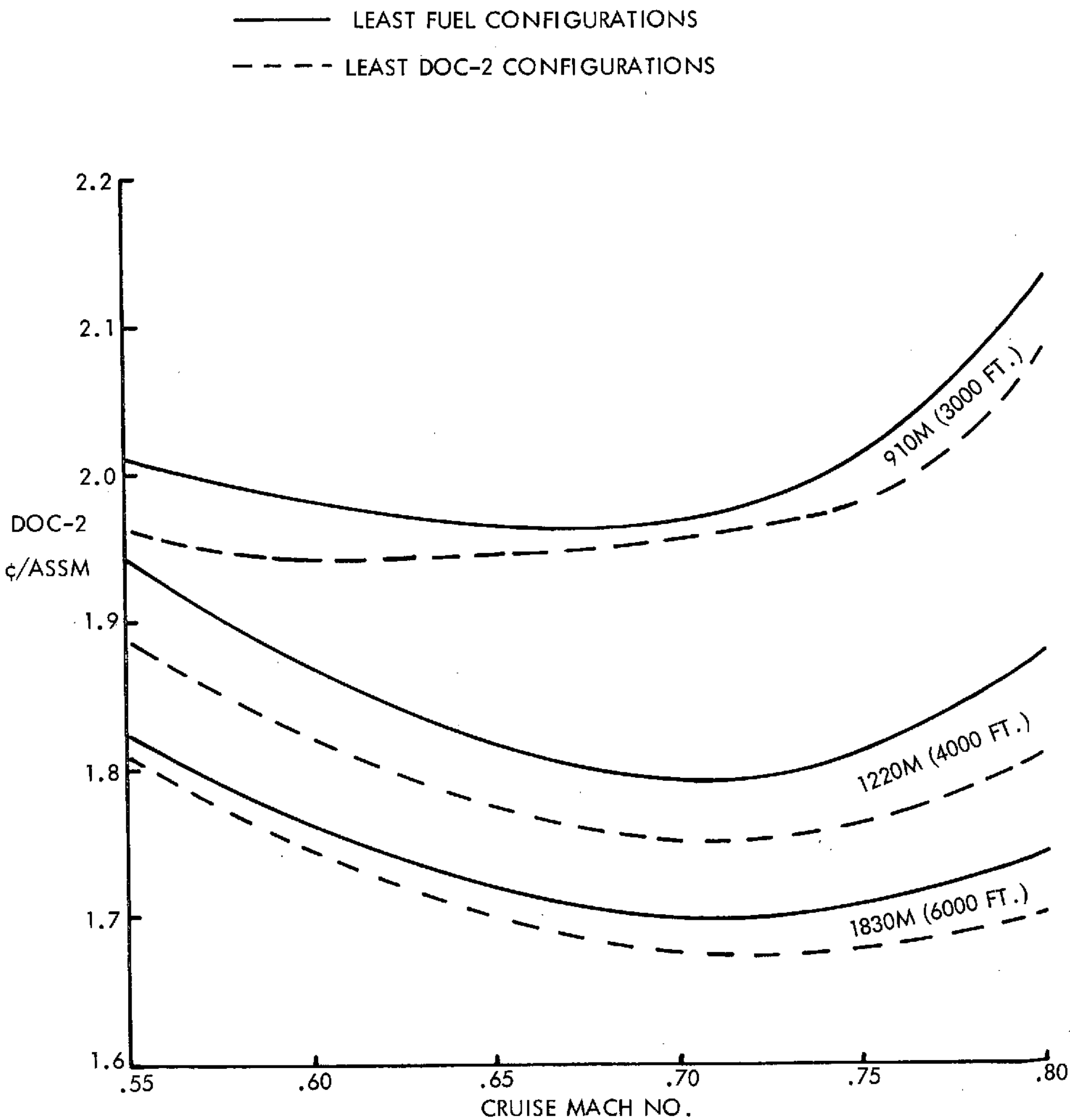

FIGURE 233 1.35 FPR MF: DOC-2 VS CRUISE MACH NO.: 4-ENGINES

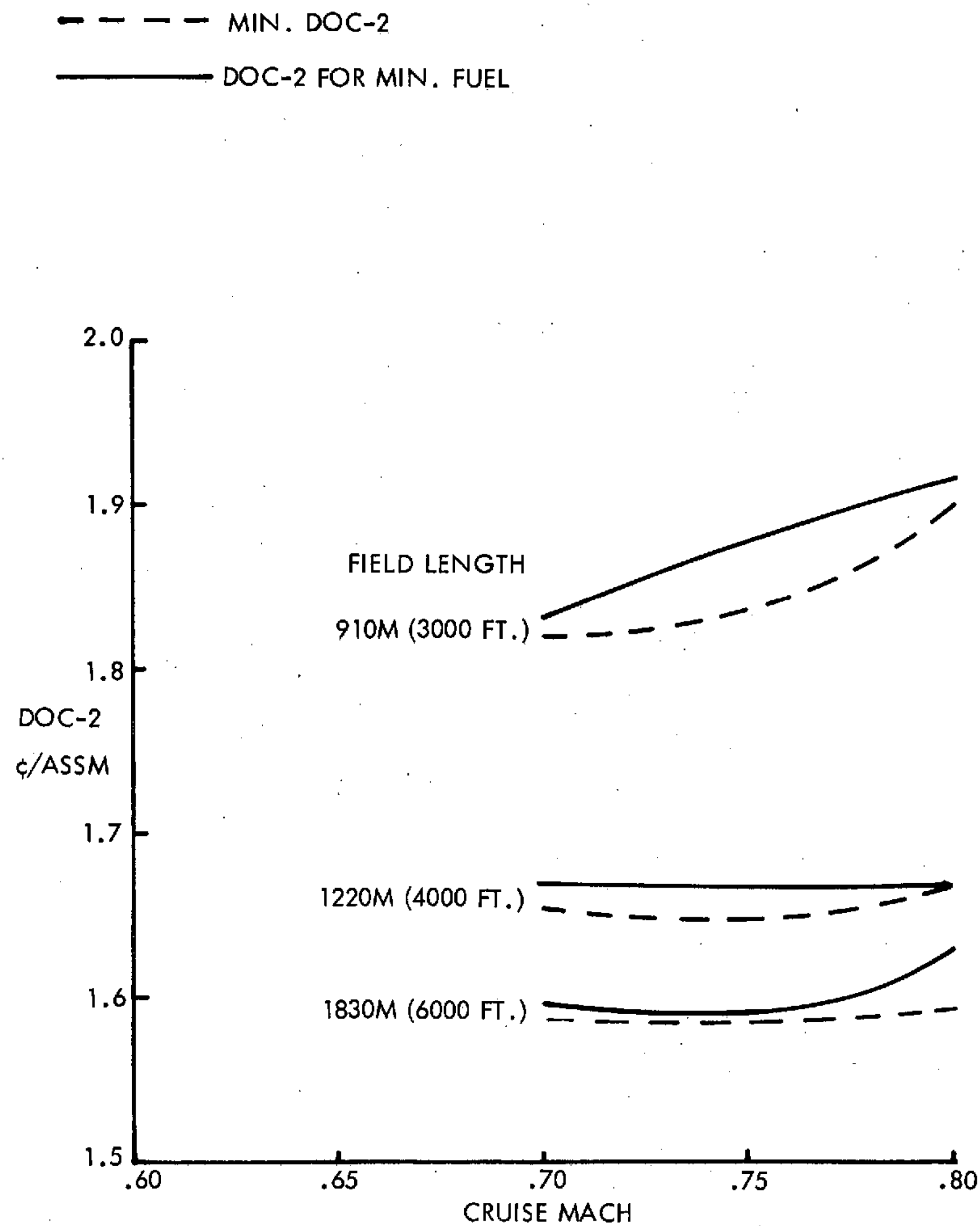

FIGURE 234 1.35 FPR MF: DOC-2 VS CRUISE MACH: 2-ENGINE

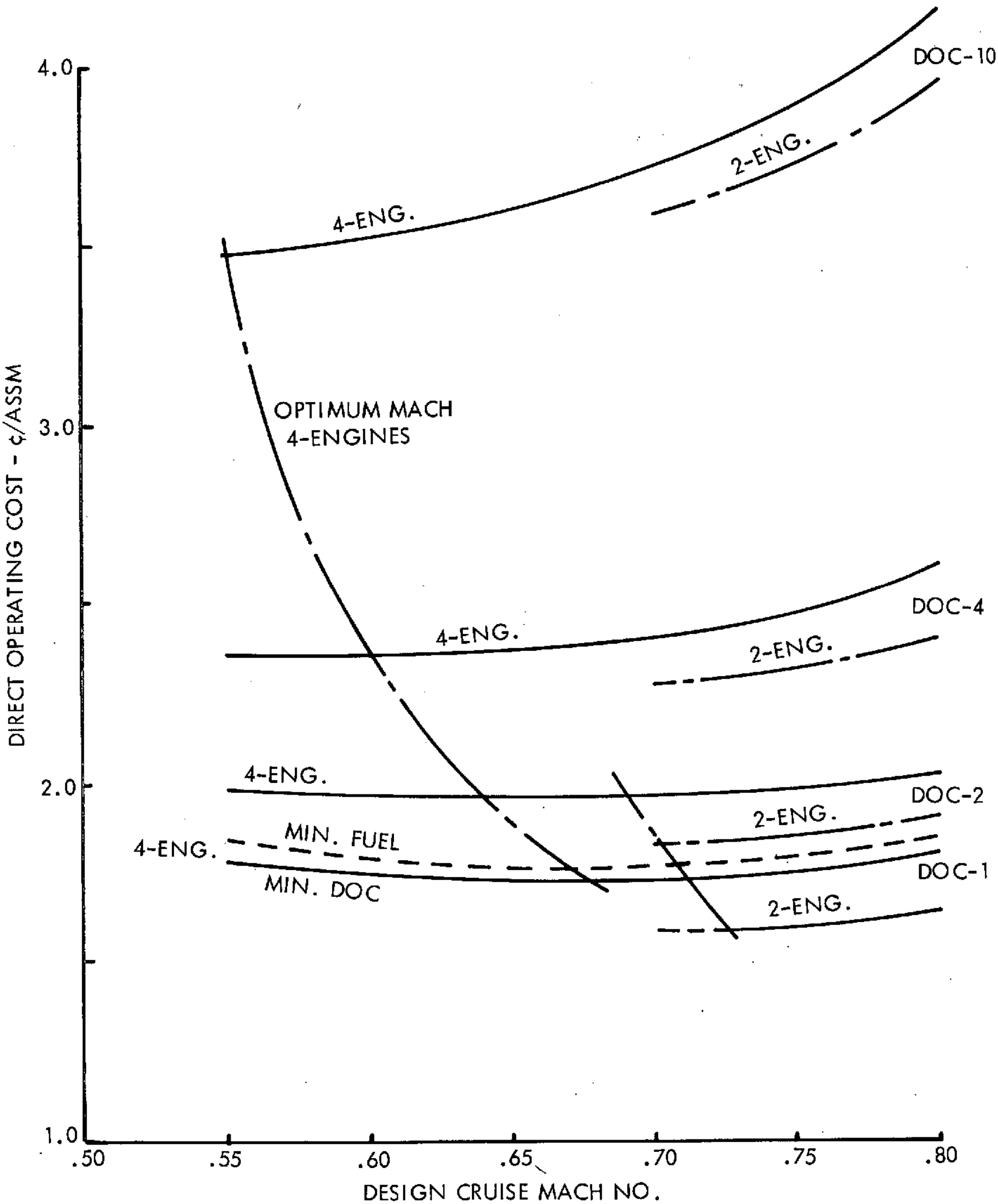

FIGURE 235 MF 1.35 FPR DIRECT OPERATING COST VS DESIGN CRUISE MACH NO., 910M (3000 FT.) FIELD LENGTH

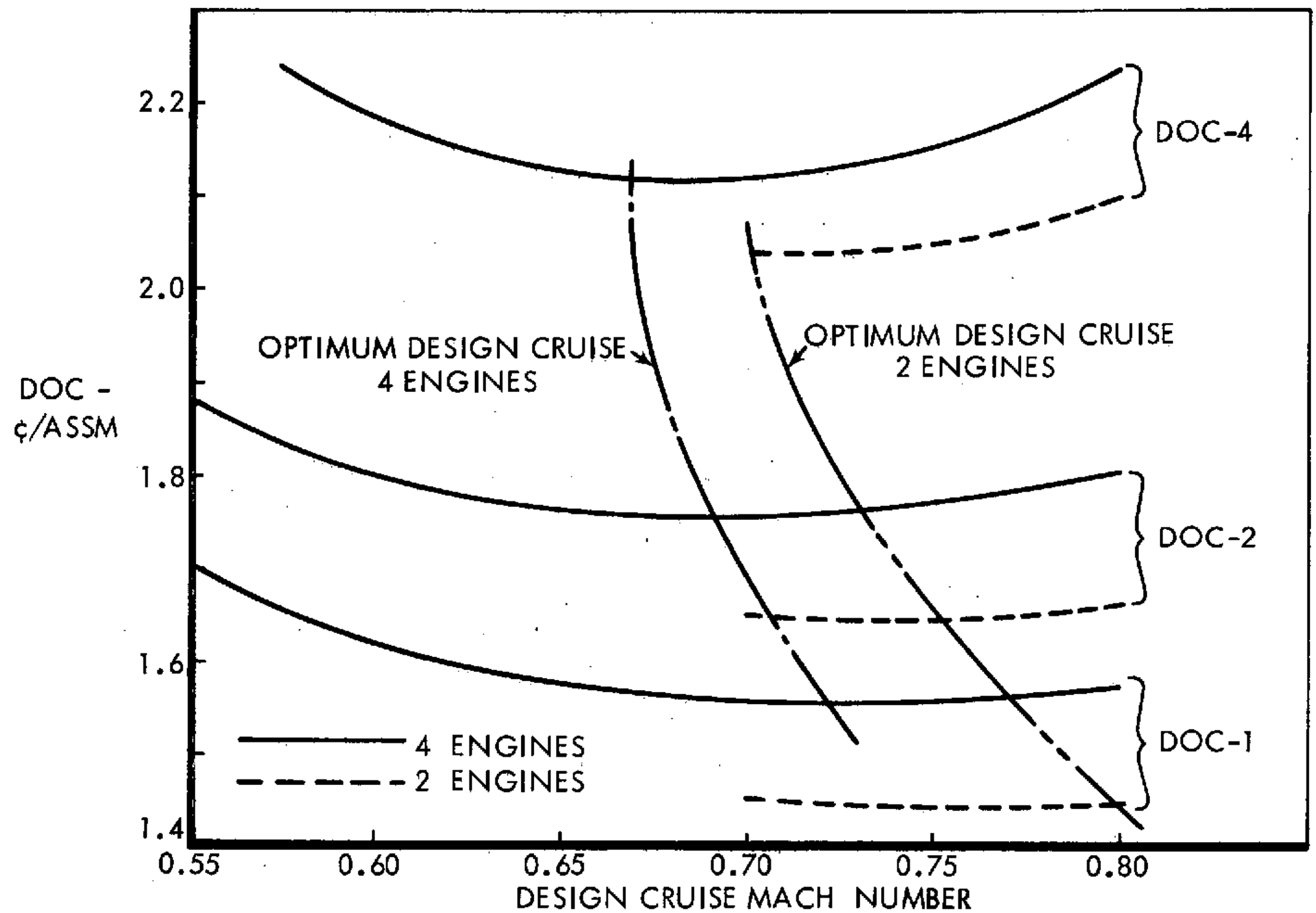

FIGURE 236 EFFECT OF FUEL PRICE ON OPTIMUM DESIGN CRUISE SPEED
1220M (4000 FT.) FIELD LENGTH MF

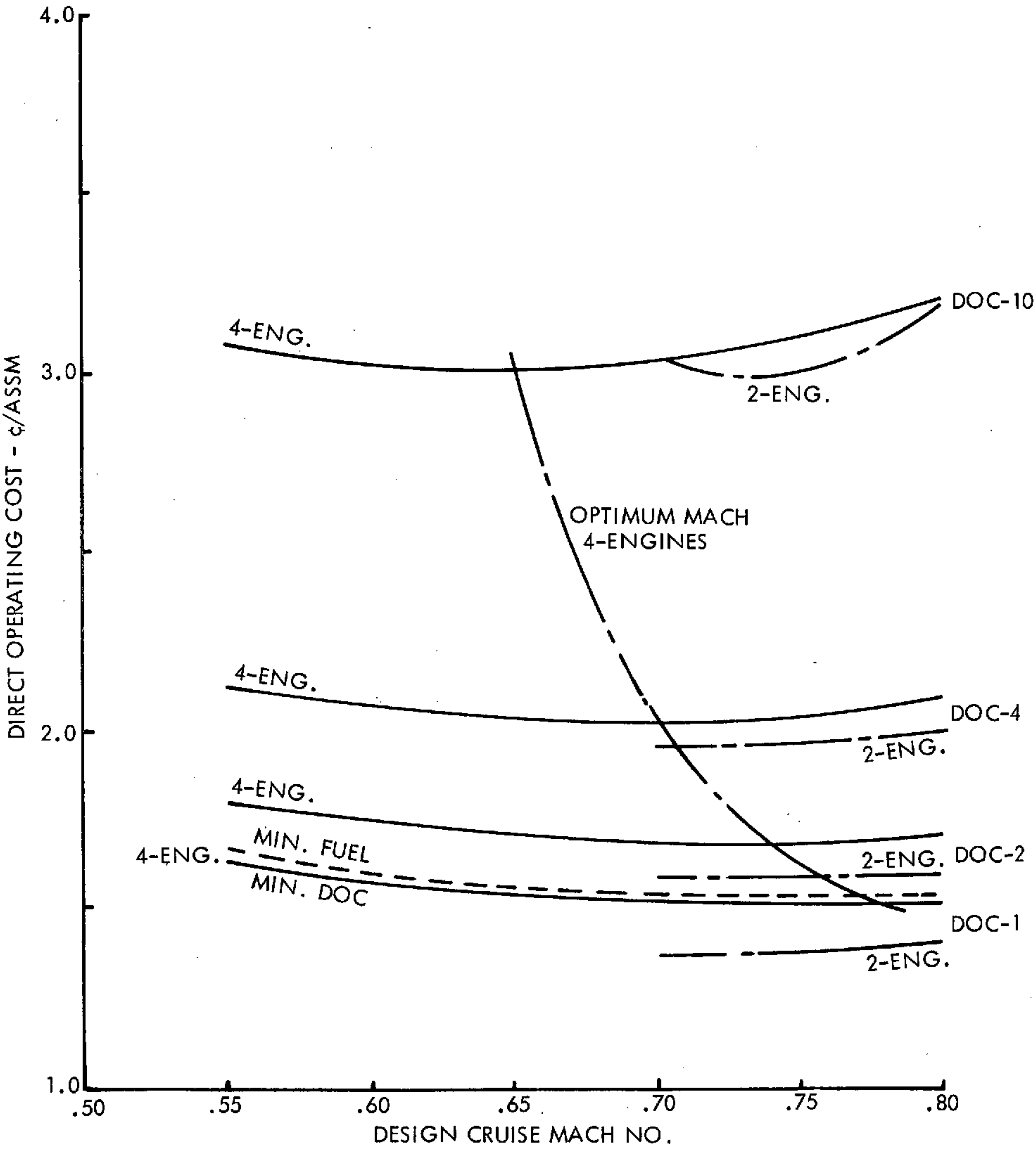

FIGURE 237 MF 1.35 FPR DIRECT OPERATING COST VS DESIGN CRUISE MACH NO., 1830M (6000 FT.) FIELD LENGTH

Although configurations can be optimized to provide minimum fuel consumption, it is probable that direct operating cost will ultimately prevail as the prime configuration selection criterion. In each of Figures 231 through 234 alternate configuration criteria are presented in terms of least mission fuel and least DOC-2 (DOC at 2 X base fuel cost). Although the least DOC-2 configurations have only marginally high fuel consumption, the DOC-2 of the 'least cost' 2-engine configurations is from 7-10% lower than that of the 4-engine minimum fuel consumption configurations at each Mach number and field length.

Figure 238 presents mission fuel plotted against aspect ratio for three Mach numbers for the 1220 m. (4000 ft.), 2- and 4-engine arrangements on the premise that the foregoing argument warrants the exclusion of 'least-fuel' vehicles per se. It is apparent that minimum fuel consumption is achieved with aspect ratio 14 for the 4-engine vehicle and approximately aspect ratio 10 for the 2-engine vehicle. Figure 239 presents DOC-1, -2, -4 and -10 plotted against aspect ratio for 2- and 4-engine airplanes at 0.75 M and 1220 m. (4000 ft.) field length. The increase in optimum aspect ratio as the fuel price increases can be seen. Comparison of the two figures shows that minimum fuel consumption is obtained at aspect ratio 14 with a 4-engine configuration while optimum DOC-2 is obtained at aspect ratio 10 with a 2-engine configuration. Using this aspect ratio 10, 2-engine, configuration as the basepoint, Figure 240 presents percentage DOC penalty versus aspect ratio. The figure illustrates the large DOC penalties of the 4-engine configuration except at the highest fuel price. It also illustrates the increase in optimum aspect ratio with increase in fuel price. It appears from the figure that the 2-engine configuration could be improved slightly at the highest fuel price by increasing aspect ratio beyond 10.

6.5.2 FPR 1.25 Configurations

Because of the initial emphasis on minimum fuel consumption, only 4-engine configurations have been sized as in the case of the OTW/IBF. Because of the very high lapse rate of this engine it was considered probable that these airplanes would be cruise

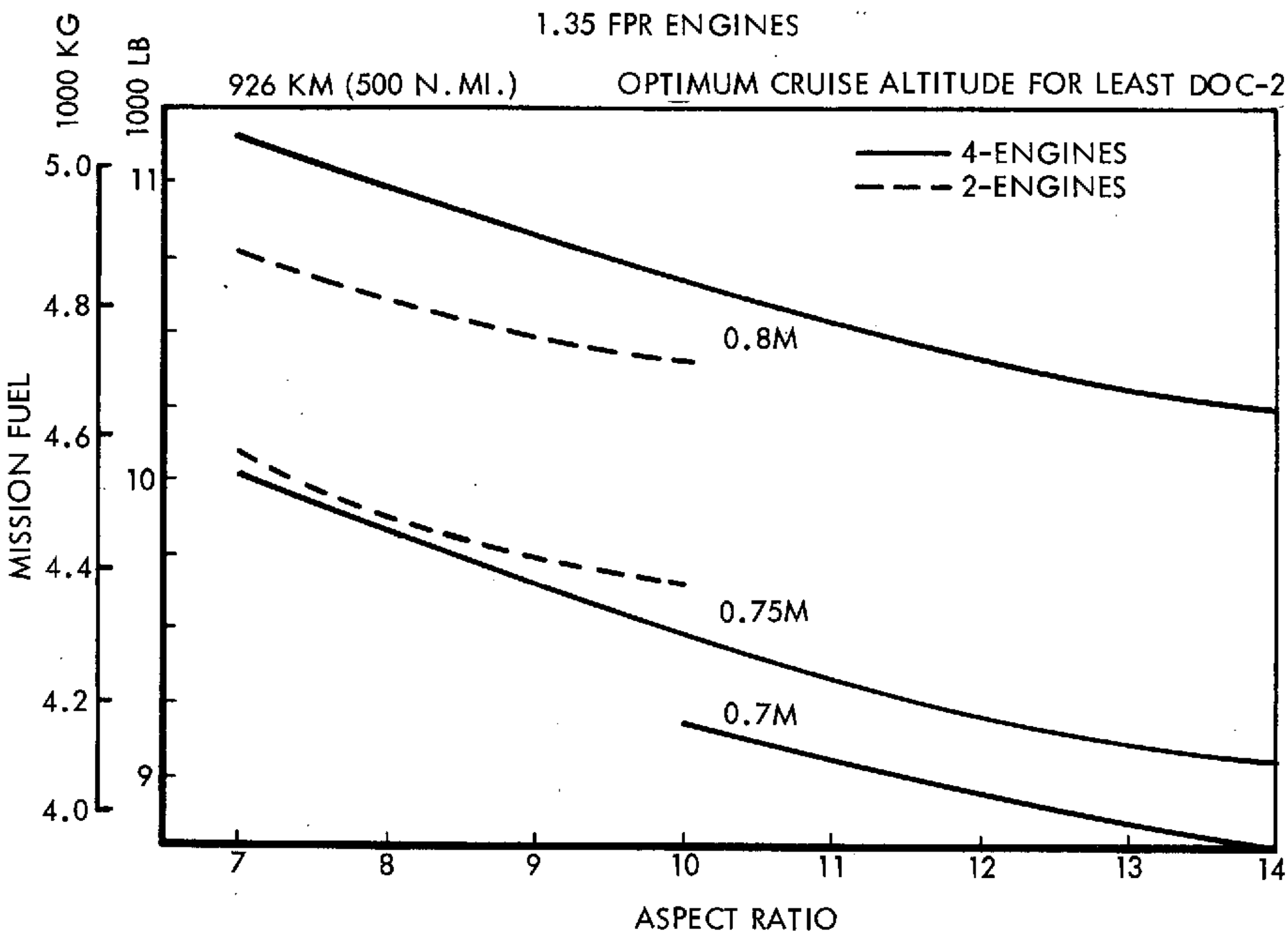

FIGURE 238 MISSION FUEL VS ASPECT RATIO - 1220M (4000 FT.) MF

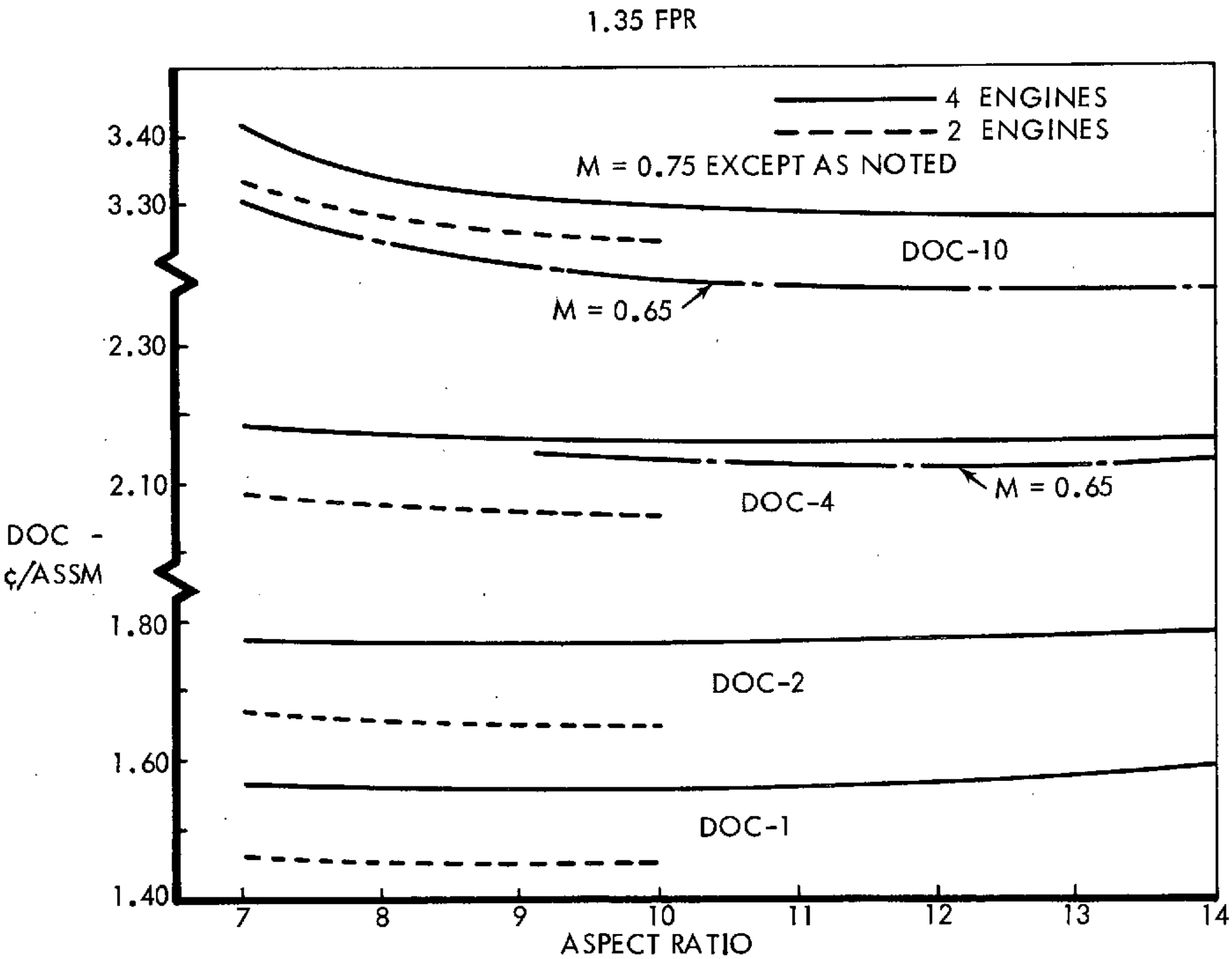

FIGURE 239 ASPECT RATIO OPTIMIZATION: 1220M (4000 FT.) MF

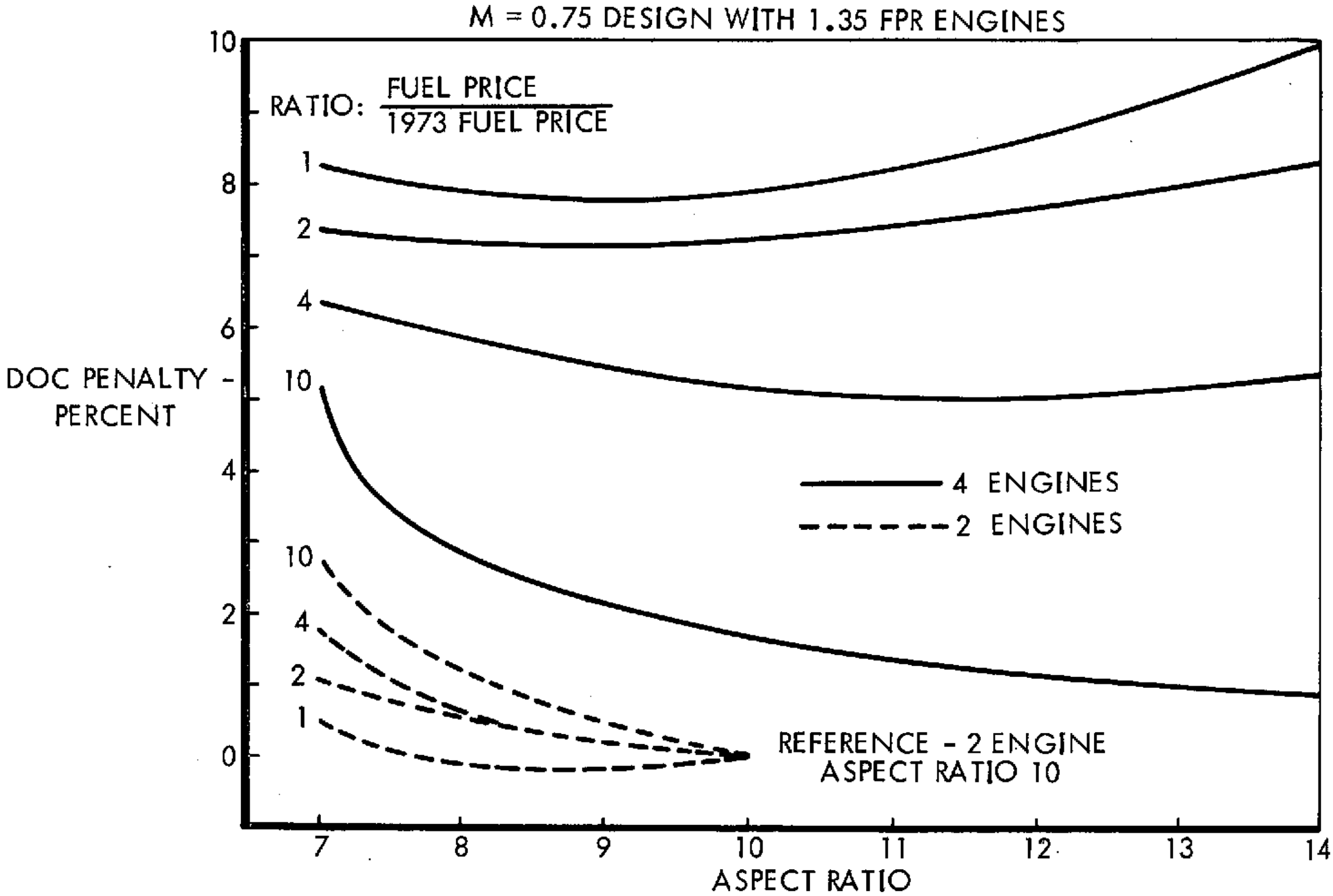

FIGURE 240 DOC PENALTY VS ASPECT RATIO: 1220M (4000 FT.) MF

critical at the higher Mach numbers and would thus favor a 2-engine arrangement for minimum DOC at these speeds.

The data generated permit the comparison of 4-engined 1.25 FPR configurations with the equivalent 1.35 FPR 4-engined and 2-engined arrangements. Section 6.5.4 indicates the superiority of the 1.35 FPR and unless very low noise is the critical criterion it is unlikely that the 2-engined 1.25 FPR configurations would be so greatly superior to the equivalent 2-engine FPR 1.35 vehicles and the 4-engine FPR 1.35 vehicles that the conclusions determined would be radically different if actual 2-engined cases for FPR 1.25 had been computed.

Figure 241 presents mission fuel versus cruise altitude for a range of Mach numbers and field lengths. For all Mach numbers higher than 0.65, the optimum altitude is between 9140 m. (30,000 ft.) and 10,670 m. (35,000 ft.). The large reductions in fuel consumption obtained by increasing field length and/or Mach number are shown. It is interesting to note that a 0.8 M, 1220 m. (4000 ft.) field length configuration has a similar fuel consumption to a 0.65 M, 910 m. (3000 ft.) field length design. Field length is very critical to economic design of the MF concept due to the very low wing loading of less than 283 Kg/m^2 (58 lb/sq.ft.) which is required for field lengths 910 m. (3000 ft.) or shorter. Figure 242 shows DOC at a fuel cost of 23¢/gallon plotted against cruise altitude for a range of Mach numbers and field lengths. The significant point is that the high Mach number concepts optimize at altitudes compatible with the minimum fuel designs whereas the lower Mach number configurations optimize for DOC at lower altitudes than are needed for minimum fuel consumption.

Figure 243 shows mission fuel versus design Mach number for 910 m. (3000 ft.), 1220 m. (4000 ft., and 1820 m. (6000 ft.) field lengths for airplanes optimized for "minimum fuel" and those designed for minimum DOC at 23¢/gallon of fuel. As expected, the fuel consumption continuously decreases with decrease in Mach number and with increase in field length. However, note the very large reduction in fuel consumption for 0.70 through 0.8 M between 910 m. (3000 ft.) and 1210 m. (4000 ft.) field lengths. Figure 244 presents DOC at a fuel cost of 11.5¢/gallon versus design cruise Mach

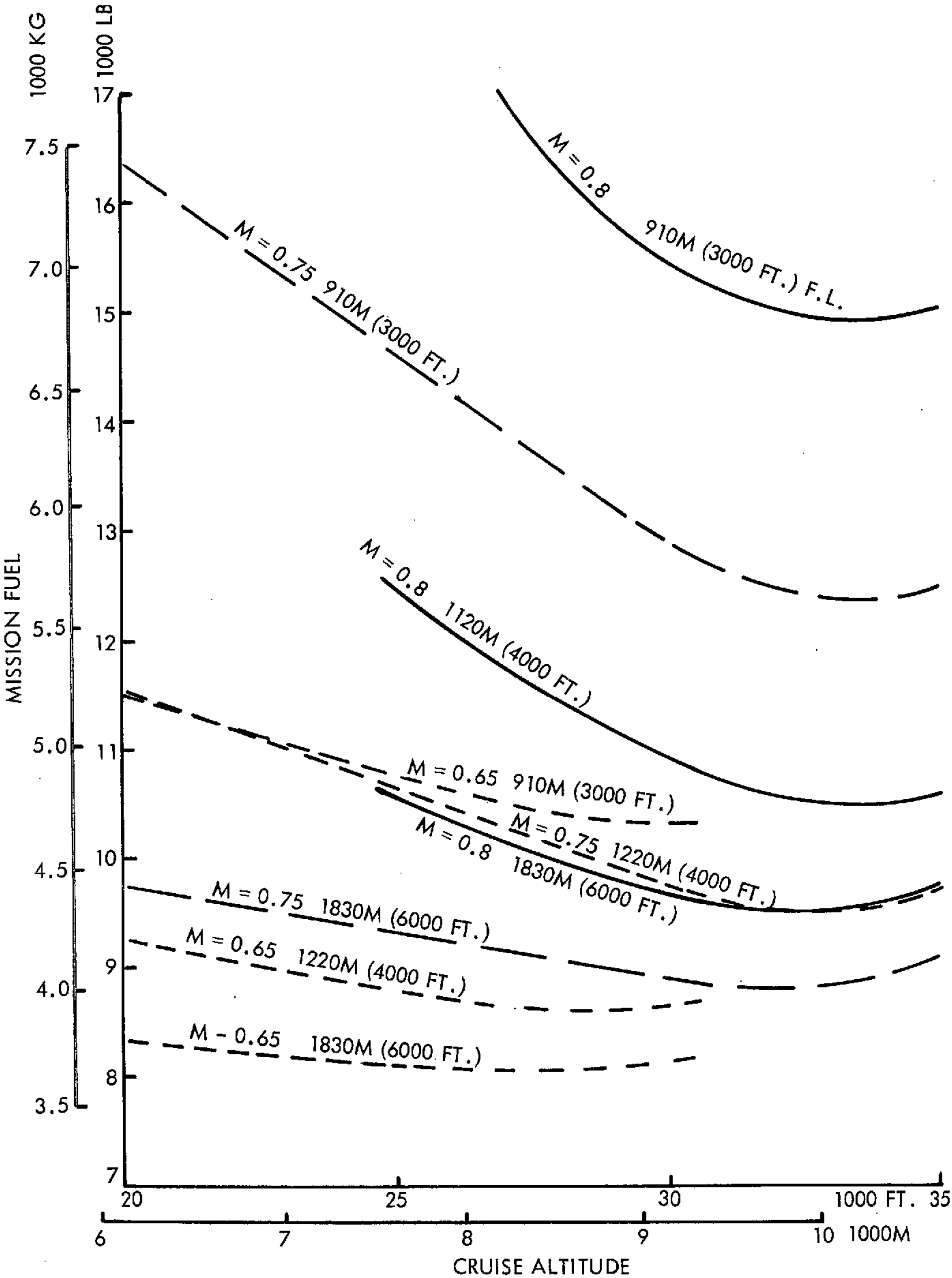

FIGURE 241 1.25 FPR MF: MISSION FUEL VS CRUISE ALTITUDE: 4-ENGINES

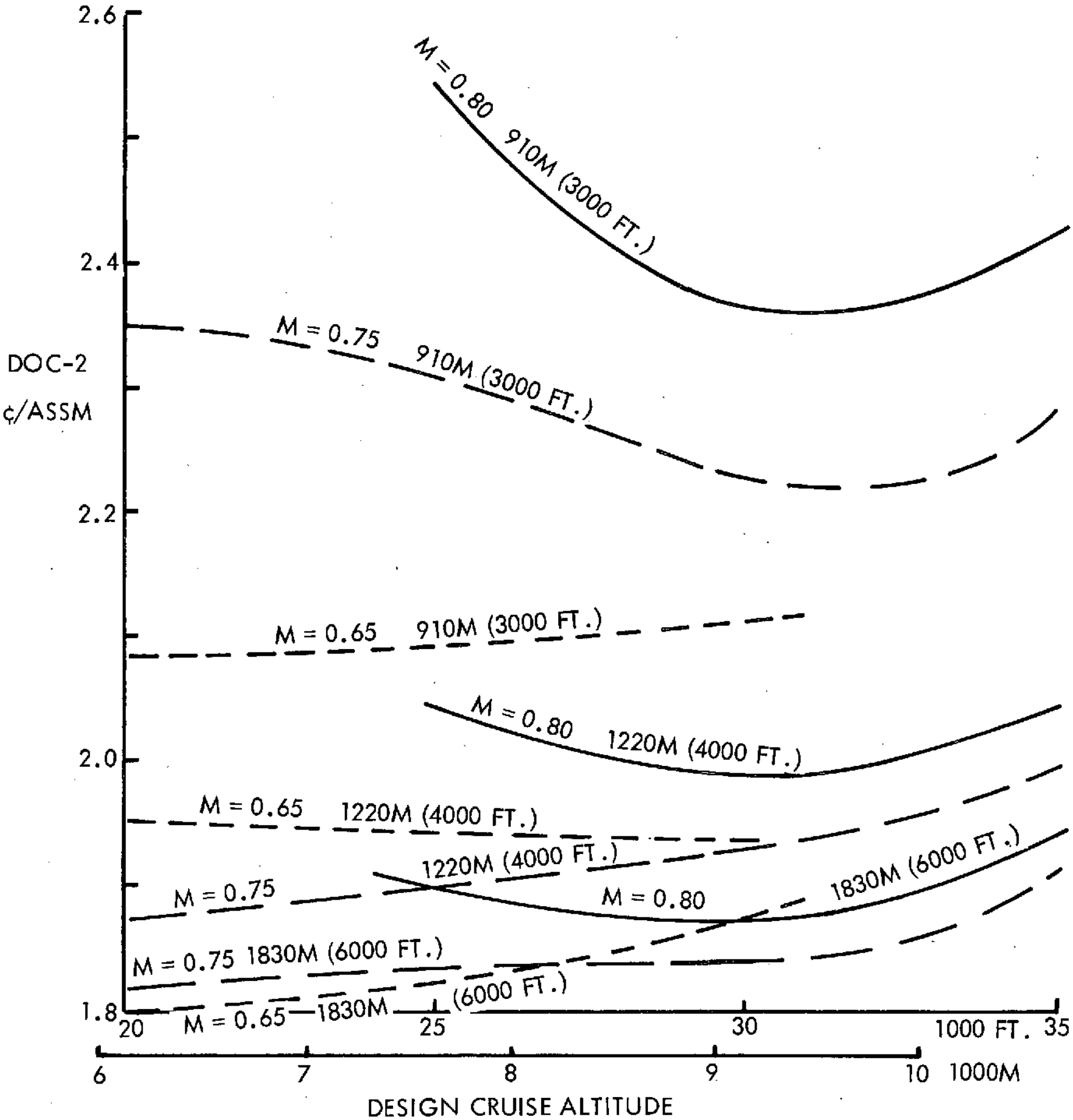

FIGURE 242 1.25 FPR MF: DOC-2 VS CRUISE ALTITUDE: 4-ENGINES

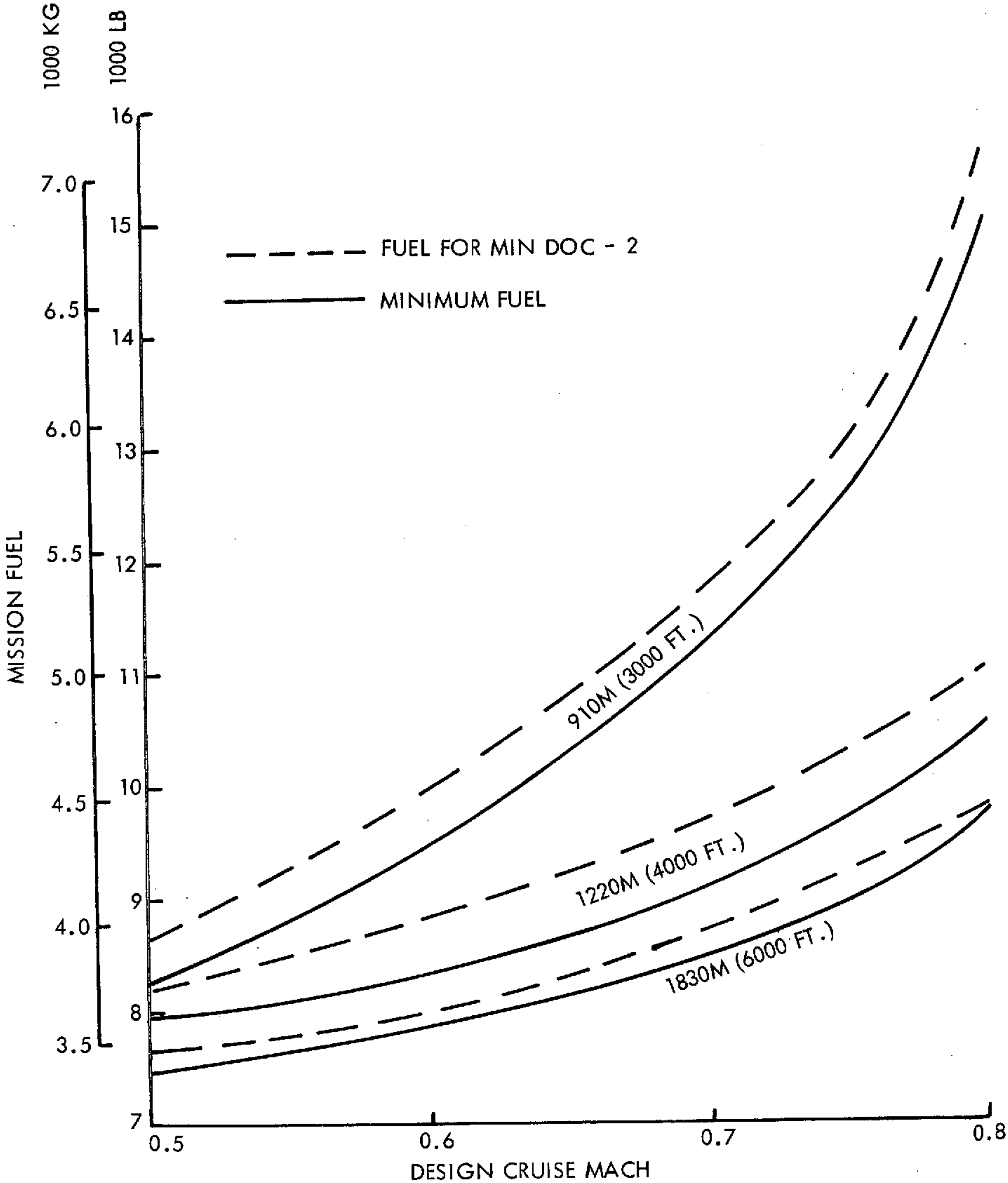

FIGURE 243 1.25 FPR MF - MISSION FUEL VS. MACH NO.: 4-ENGINES

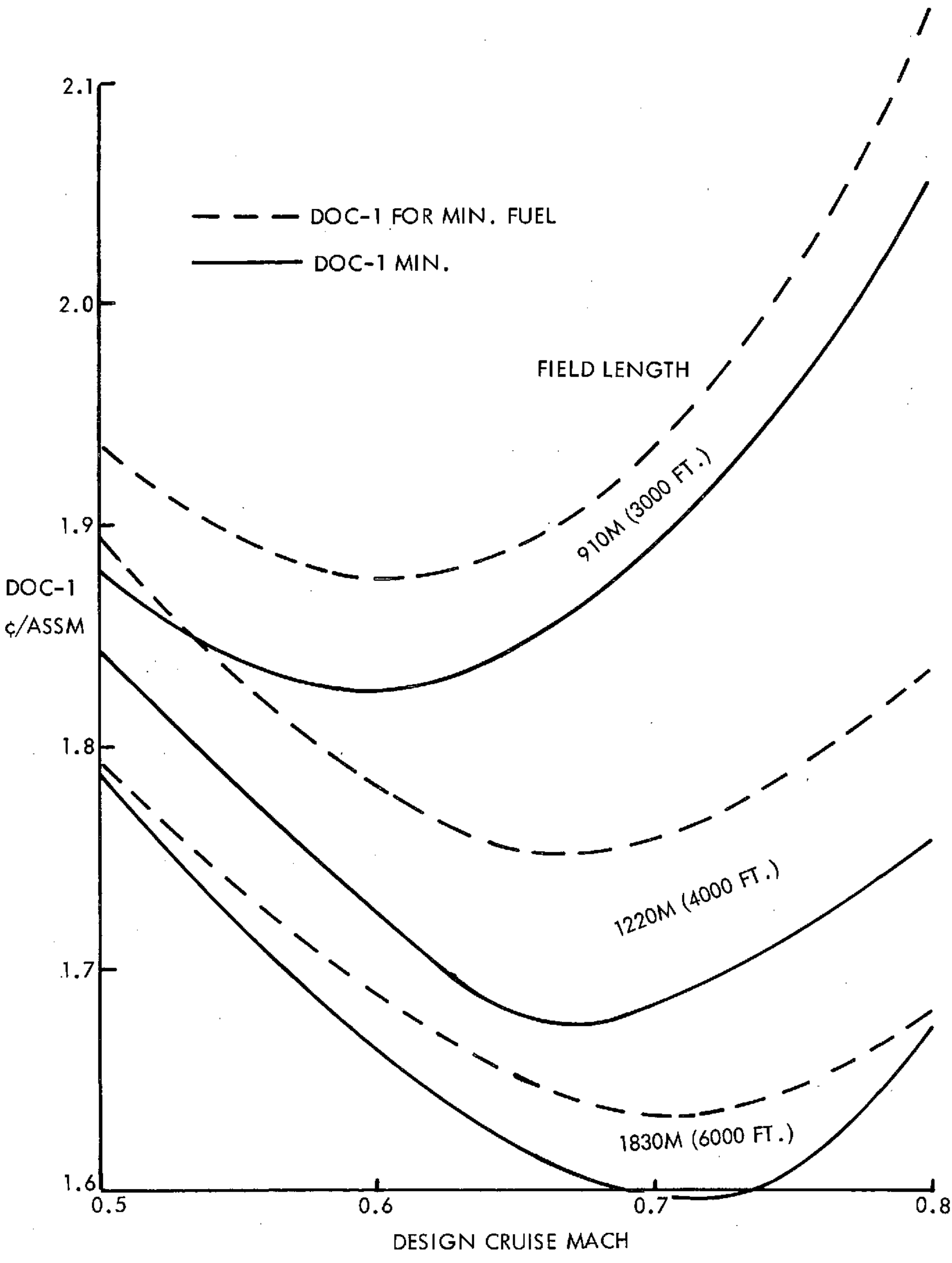

FIGURE 244 1.25 FPR MF DOC-1 VS MACH NO.: 4-ENG.

number for field lengths 910 m. (3000 ft.), 1220 M. (4000 ft.), and 1820 m. (6000 ft.) for "minimum DOC" and "minimum fuel" airplanes. Figures 245 and 246 present similar data for fuel costs of 23¢ and 46¢/gallon respectively. Unlike the mission fuel, the DOC buckets sharply due to the beneficial effect of lower fuel consumption being offset by the adverse effect on DOC of speed reduction. Note that the bucket occurs at lower Mach numbers as the effect of the higher fuel cost impacts the DOC computation.

6.5.3 1.47 FPR Configurations

For the reasons already discussed, primary emphasis was placed on 4-engine vehicles. The lower lapse rate will favor the 4-engine arrangement more at this FPR than at 1.35 FPR. Thus, the 2-engine arrangement is only likely to be advantageous at the longer field lengths and lower fuel prices.

Mission fuel minimized at an aspect ratio of approximately 10 for all Mach numbers and cruise altitudes for the 910 m. (3000 ft.) field length cases compared with 14 at all Mach numbers and cruise altitudes for the 1220 m. (4000 ft.) and 1820 m. (6000 ft.) cases. Using the optimum aspect ratio, the optimum cruise altitude for minimum fuel varied with cruise Mach number and field length as follows:

Cruise Speed	Altitude @ Field Length		
M	910 m. (3000')	1220 m. (4000')	1830 m. (6000')
0.6	9140 m. (30,000')	9140 m. (30,000')	9140 m. (30,000')
0.65	1060 m. (33,000')	9140 m. (30,000')	9140 m. (30,000')
0.7	10970 m. (36,000')	9140 m. (30,000')	9140 m. (30,000')
0.8	10970 m. (36,000')	10970 m. (36,000')	10970 m. (36,000')

Aspect ratio for minimum DOC varies with fuel cost, Mach number and field length as follows:

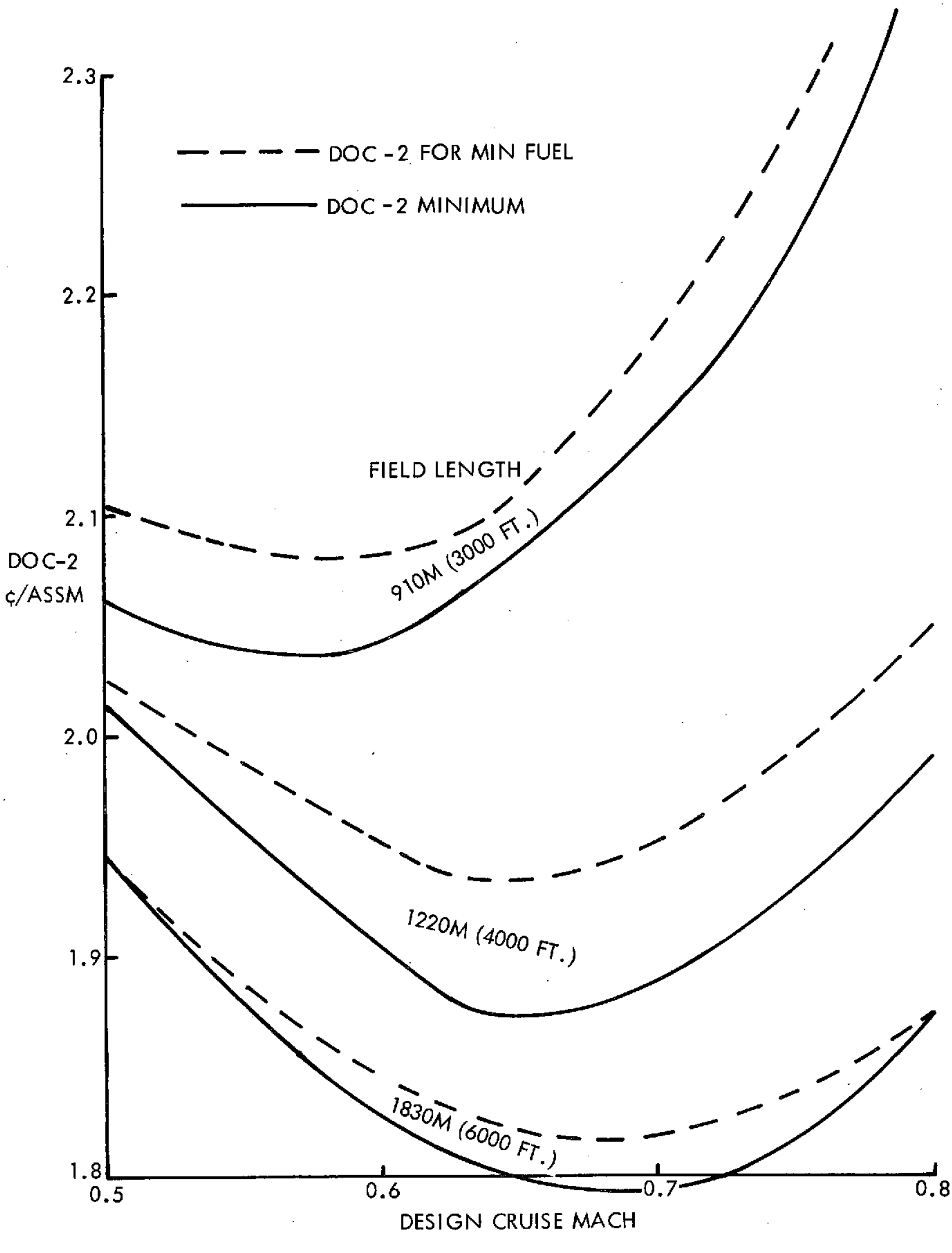

FIGURE 245 1.25 FPR MF DOC-2 VS MACH NO.: 4-ENGINES

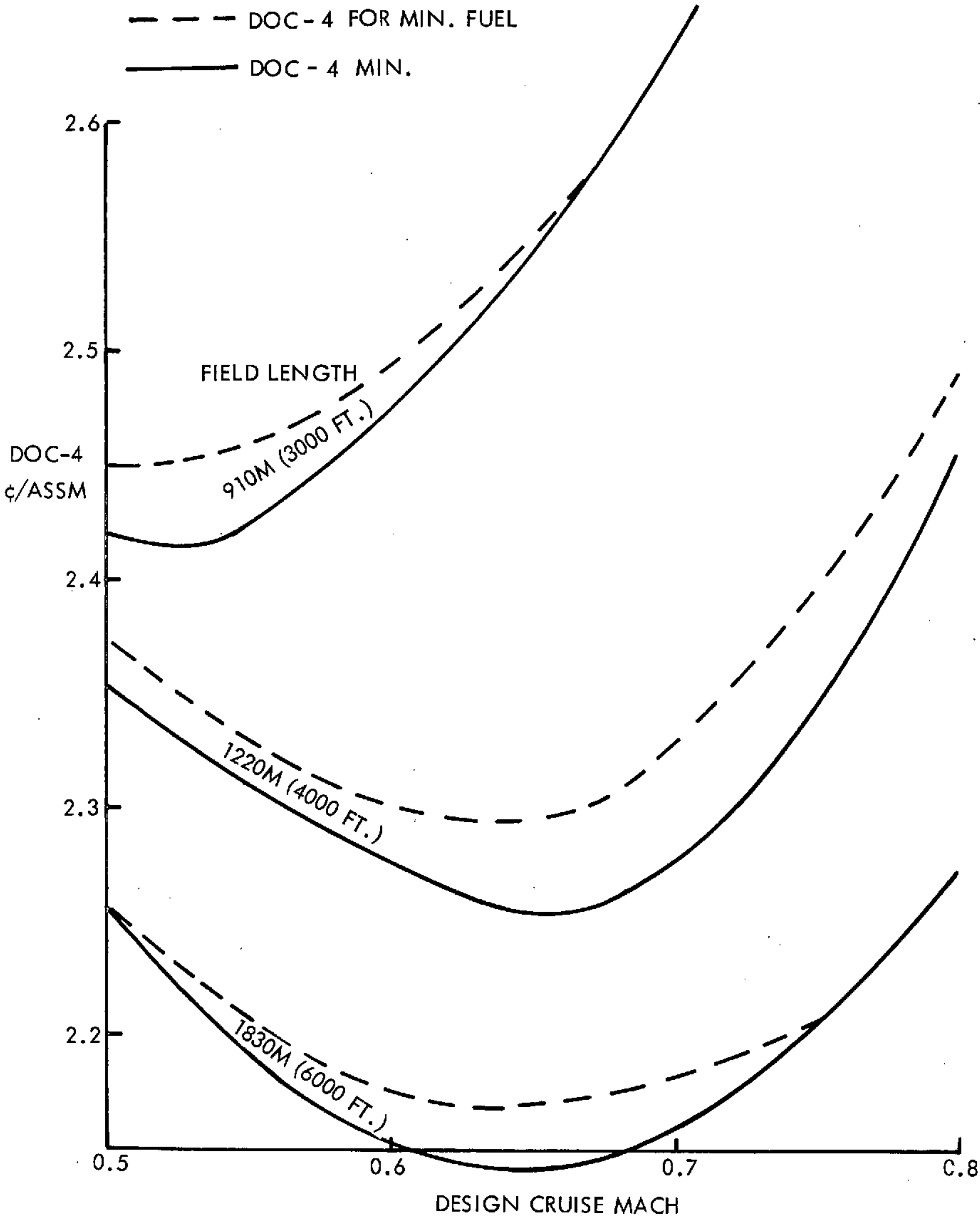

FIGURE 246 1.25 FPR MF DOC-4 VS MACH NO.: 4-ENGINES

Optimized For	Cruise Speed M	AR @ Field Length 910 m. (3000')	1220 m. (4000')	1830 m. (6000')
DOC 1	0.6	10	10	10-12
	0.8	10	11	12-14
DOC 4	0.6	10	10	14
	0.7	10	12	14
	0.8	10	12-14	14

The optimum cruise altitude in all cases was approximately 9140 m. (30,000 ft.).

Figure 247 illustrates the decrease in fuel consumption with decreasing Mach number and increasing field length. Note the large reduction in fuel from 910 m. (3000 ft.) to 1220 m. (4000 ft.) field length which is due to the higher wing loading and consequent better match between takeoff and cruise, resulting in better SFC. It should also be noted that minimum fuel consumption is not necessarily at minimum Mach number with this higher FPR.

Figures 248 and 249 presents DOC-1 and DOC-4 versus cruise Mach number. The conclusions drawn are similar to those of the other fan pressure ratios.

6.5.4 Sensitivity to SFC and Engine Weight

Since the higher fuel consumption and direct operating cost were higher for MF aircraft with the 1.47 FPR engines than for those with the 1.35 FPR engines, other contemporary engines in the range of 1.5 to 1.6 FPR were examined. Sizing runs were made for mechanical flap aircraft with aspect ratio 14 wings at Mach 0.75 and 30,000 feet cruise altitude. The engines were represented by the following factors:

Engine	SFC Factor	Engine Wt. Factor
(A) 1.47 FPR	1.0	1.0
(B)	0.96	0.935
(C)	0.944	1.0
(D)	0.944	0.97
(E)	0.944	1.26

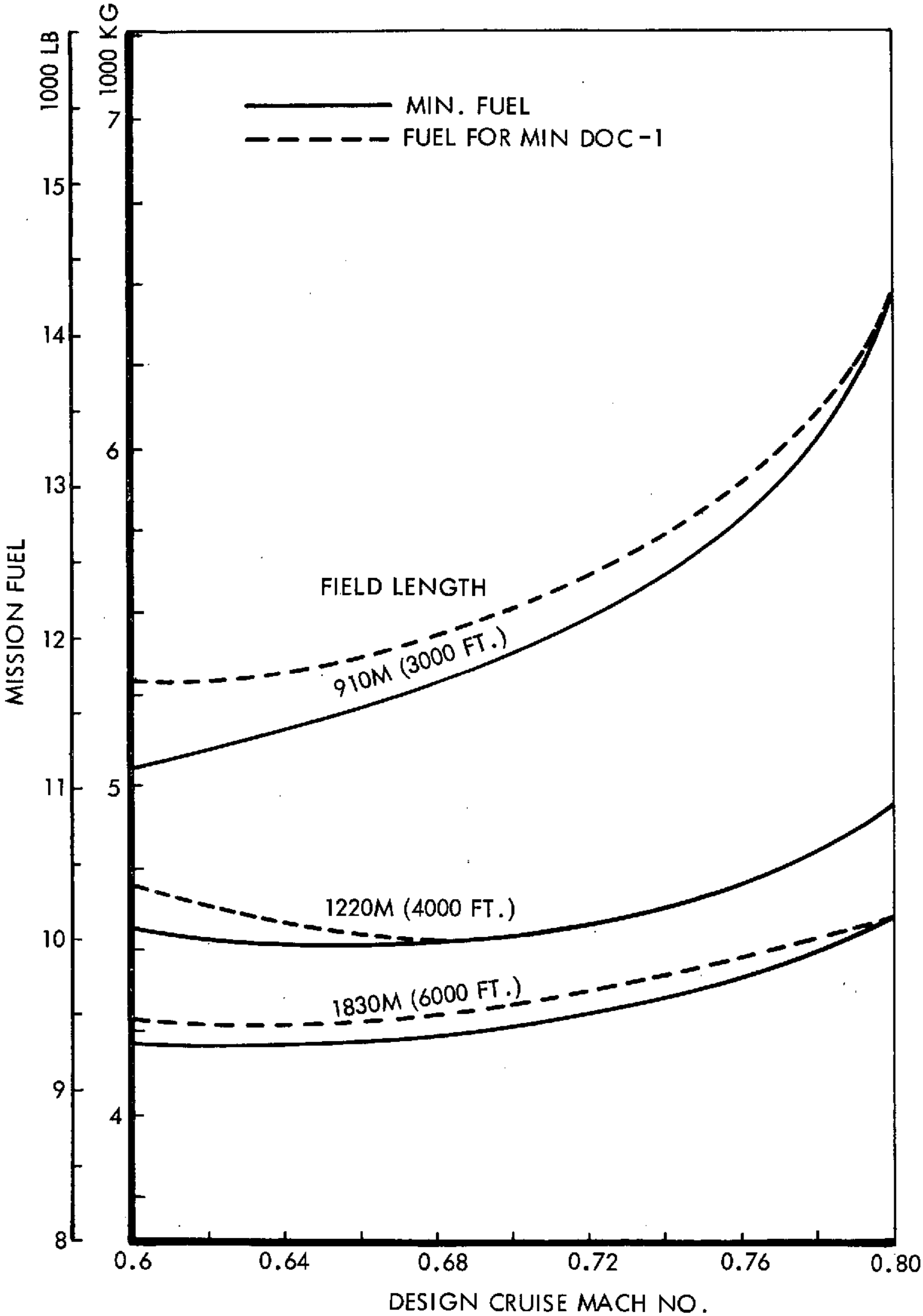

FIGURE 247 1.47 FPR MF: MISSION FUEL VS MACH NO.

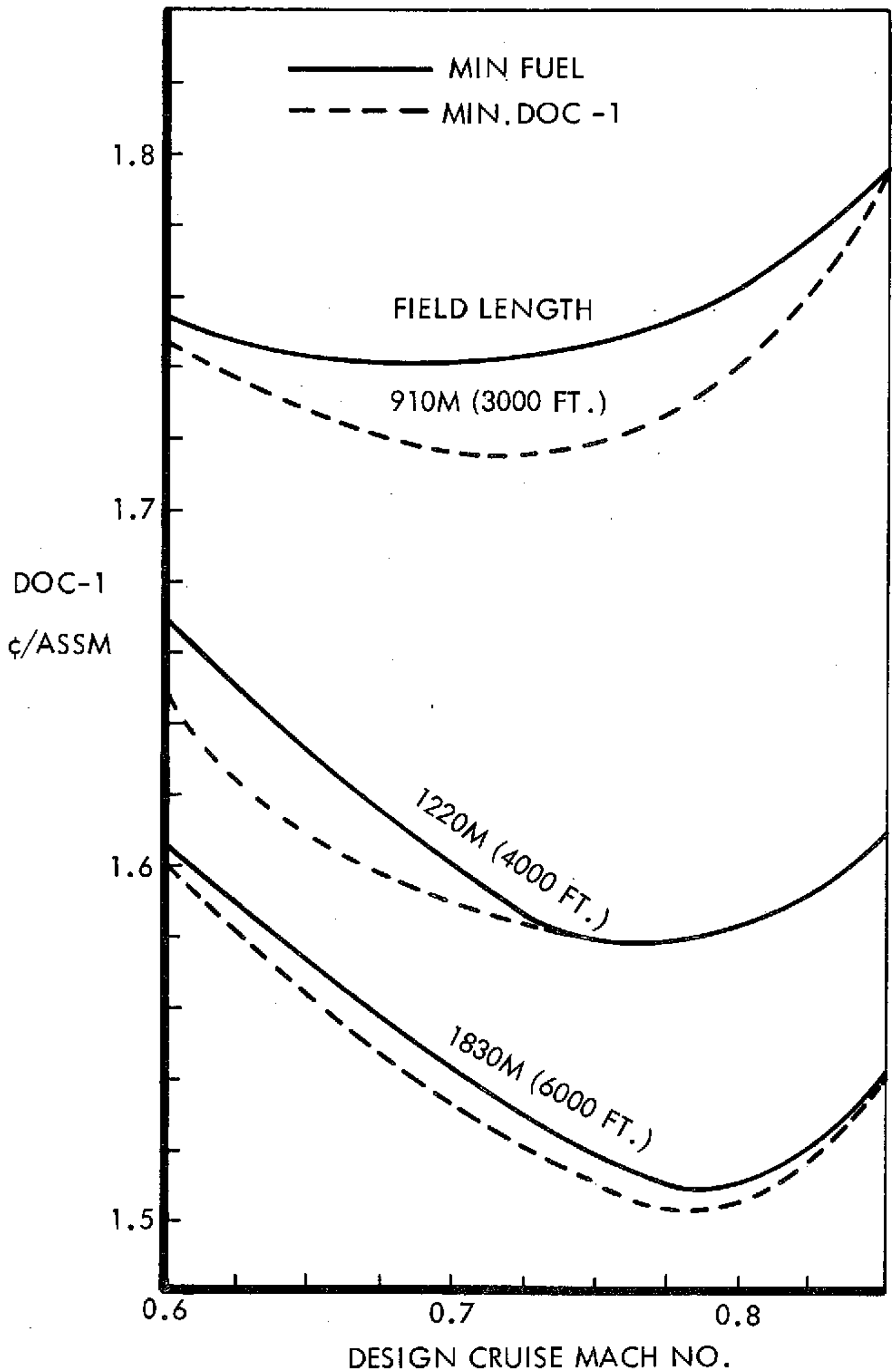

FIGURE 248 1.47 FPR MF: DOC-1 VS MACH NO.

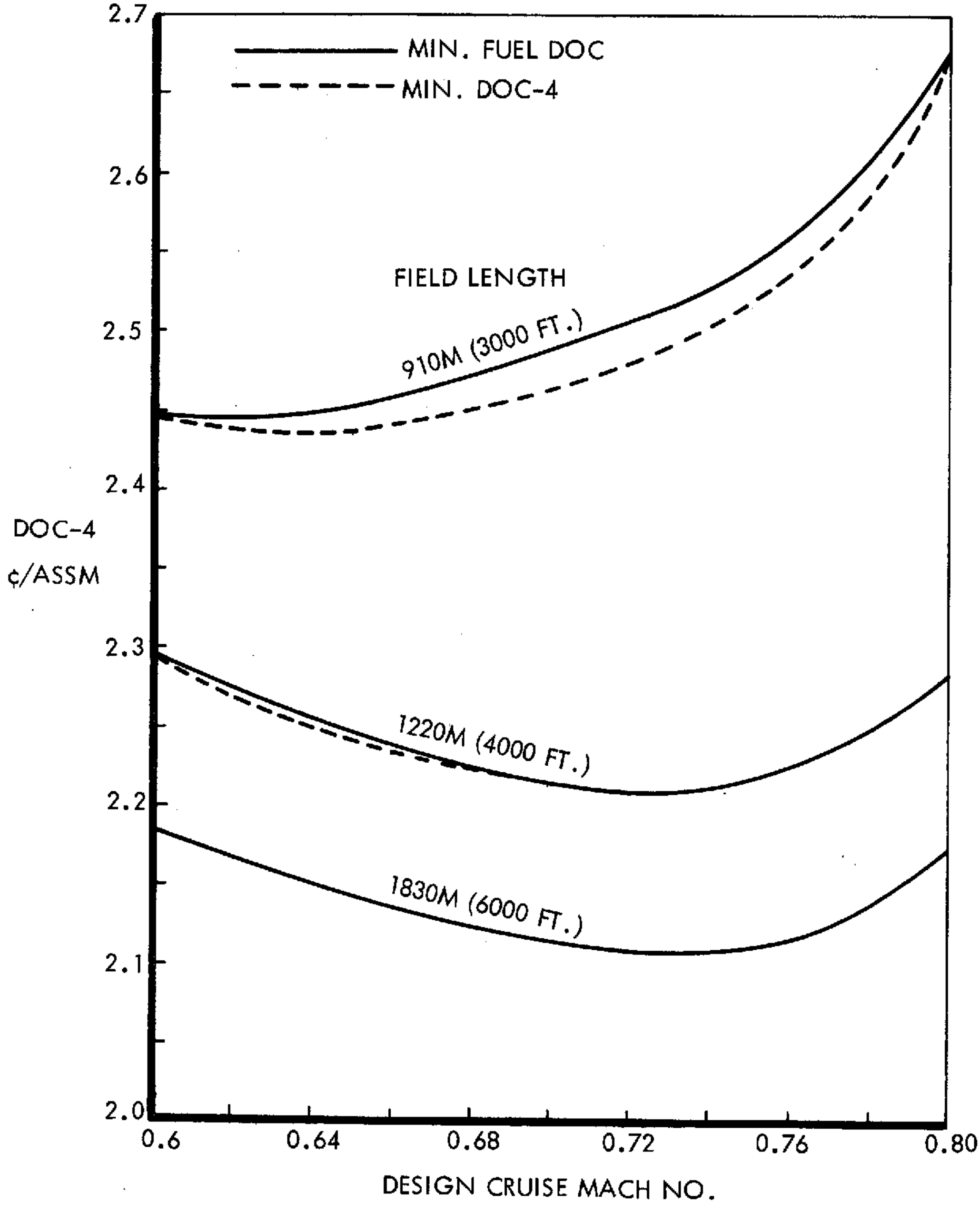

FIGURE 249 1.47 FPR MF: DOC-4 VS MACH NO.

The results indicate that for a 4000-foot field length airplane, a one percent change in SFC is equivalent in its effect on fuel consumption to an eight percent change in engine weight. Relative to DOC with fuel at 23¢ per gallon, a one percent change in SFC is equivalent to a five percent change in engine weight.

The estimated mission fuel and DOC for airplanes with current technology engines are shown in Table XXVIII for a 1210m. (4000 ft.) field length design cruising at M 0.75 and 9140 m. (30,000 ft.). For reference, an airplane with 1.35 FPR engines is also summarized. The latter is significantly superior in fuel consumption and equivalent in direct operating cost at DOC-2.

TABLE XXVIII - MISSION FUEL AND DOC FOR CURRENT TECHNOLOGY ENGINES

148 Passengers, 926 Km (500 N.M.) range, M 0.75, 9140 m. (30,000 ft.), Cruise 1220 m. (4000 ft.) Field Length, Aspect Ratio 14

Engine	Mission Fuel lb.	DOC-1	DOC-2	DOC-4	DOC-10
A	10,450	1.57	1.79	2.22	3.52
B	9,950	1.55	1.76	2.17	3.41
C	9,870	1.55	1.76	2.17	3.40
D	9,870	1.55	1.76	2.16	3.39
E	10,260	1.60	1.81	2.24	3.45
FPR 1.35 (Ref.)	8,900	1.59	1.77	2.14	3.24

6.6 MF HANDLING AND RIDE QUALITIES

The design aim from a stability and control point of view is to have the aircraft respond easily to the pilot commands and allow him to accurately control it under all flight conditions. At the same time the inherent (or seemingly inherent) riding characteristics from the passenger and pilot view point should be as smooth as possible. The criteria used as aids in design to insure that these goals are met as closely as possible have been discussed in detail in the NASA CR 114612 (Reference 2). The conventional Military Specifications, the V/STOL Military Specifications, AGARD, NASA, and Lockheed documents were consulted in arriving at these criteria. Only the critical criteria which sized controls and determined augmentation requirements are discussed here. The general discussion of the rationale behind the required margins and the complexities of STOL aircraft which make landing approach the critical flight mode have been well presented in Reference 2 and are not repeated here.

The obvious problems to be encountered with a MF STOL configuration arise from its sensitivity at an inherently low wing loading. Succeeding paragraphs discuss these problems as presented by the selected baseline mission MF with 1.35 FPR engines for a 914m. (3000 ft.) field length.

6.6.1 Handling Qualities

Longitudinal - The horizontal tail has been sized to allow a 20% MAC travel of the center of gravity. The maximum trim requirement is that at the most forward C.G. during the landing approach flight condition. In addition to providing these functions an allowable control margin above these requirements has been provided to give a maneuver capability of 0.3 rad/sec^2. The horizontal tail volume coefficient to provide this capability is 0.8. A trimmable horizontal surface with an elevator for maneuver has been selected. The required lift technology of the horizontal is rather modest calling for a $C_{L\ MAX}$ of 1.3. The aft C.G. limit for this configuration is approximately 50% MAC and a 5% static margin is provided at that aft C.G.

The augumented longitudinal dynamic stability is shown in Figure 250 for the aft C.G. on the landing approach. The acceptability criteria shown here are those of MIL-F-83300. Although this configuration does satisfy the specified criteria, the short period mode is aperiodic and an augmentation system would be desirable to reduce pilot work load.

Lateral-Directional - The lateral design requirement is to provide a roll acceleration capability of 0.42 rad/sec^2 at the landing approach in symmetric flight. An additional requirement is to retain 30 percent of this control power for maneuvering after trimming a critical engine failure in a 25 knot crosswind at the approach speed. The control power (rolling moment coefficient) required for the design acceleration is 0.1 at the approach speed of 200 Km/hr (108 knots). The corresponding roll power to balance an engine out in a 25 degree sideslip is 0.14. This low speed criterion could be satisfied by either large ailerons or conventional ailerons supplemented by spoilers. However, because of flexibility effects at higher speeds, spoilers become mandatory and are used in conjunction with the smaller ailerons in the landing approach.

The minimum control speed at the landing weight leads to the critical level of rudder power. The baseline vehicle has a yaw acceleration capability of 0.3 rad/sec^2 in the symmetric case for which the criteria adopted demand a minimum of 0.16 rad/sec^2.

The dynamic stability of the lateral directional dutch roll mode is presented in Figure 251 which indicates that the criteria of MIL-F-83300 are met. The spiral mode is unstable with a time to double amplitude of 31 seconds. The roll time constant is 1.1 seconds. Thus stability augmentation will probably be required for good turn coordination.

6.6.2 Ride Quality Analysis

A ride quality analysis has been conducted for the three flight conditions specified in the original Statement of Work. The specified RMS gust levels of 1.7m./sec. (5.7 ft./sec.) for the M = 0.8 cruise at 9140m. (30,000 ft.), 2.5 m./sec. (8.2 ft./sec.) for the descent case of 463 km/hr. (250 knots) at 1520m. (5000 ft.), and 3.0m./sec.

MECHANICAL FLAP CONFIGURATION
LANDING APPROACH

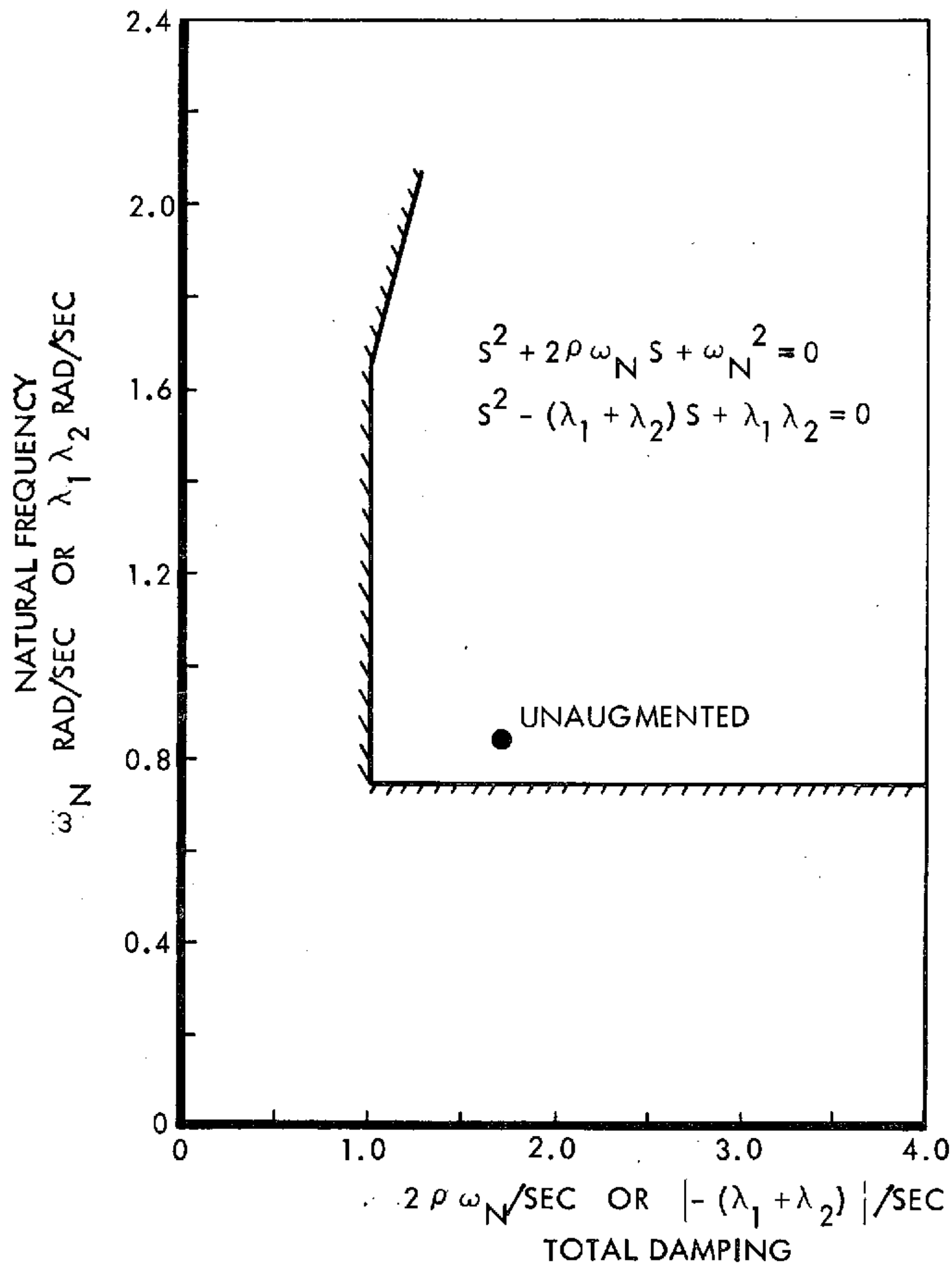

FIGURE 250 LONGITUDINAL SHORT TERM MODE REQUIREMENTS (MF)

MECHANICAL FLAP CONFIGURATION
LANDING APPROACH

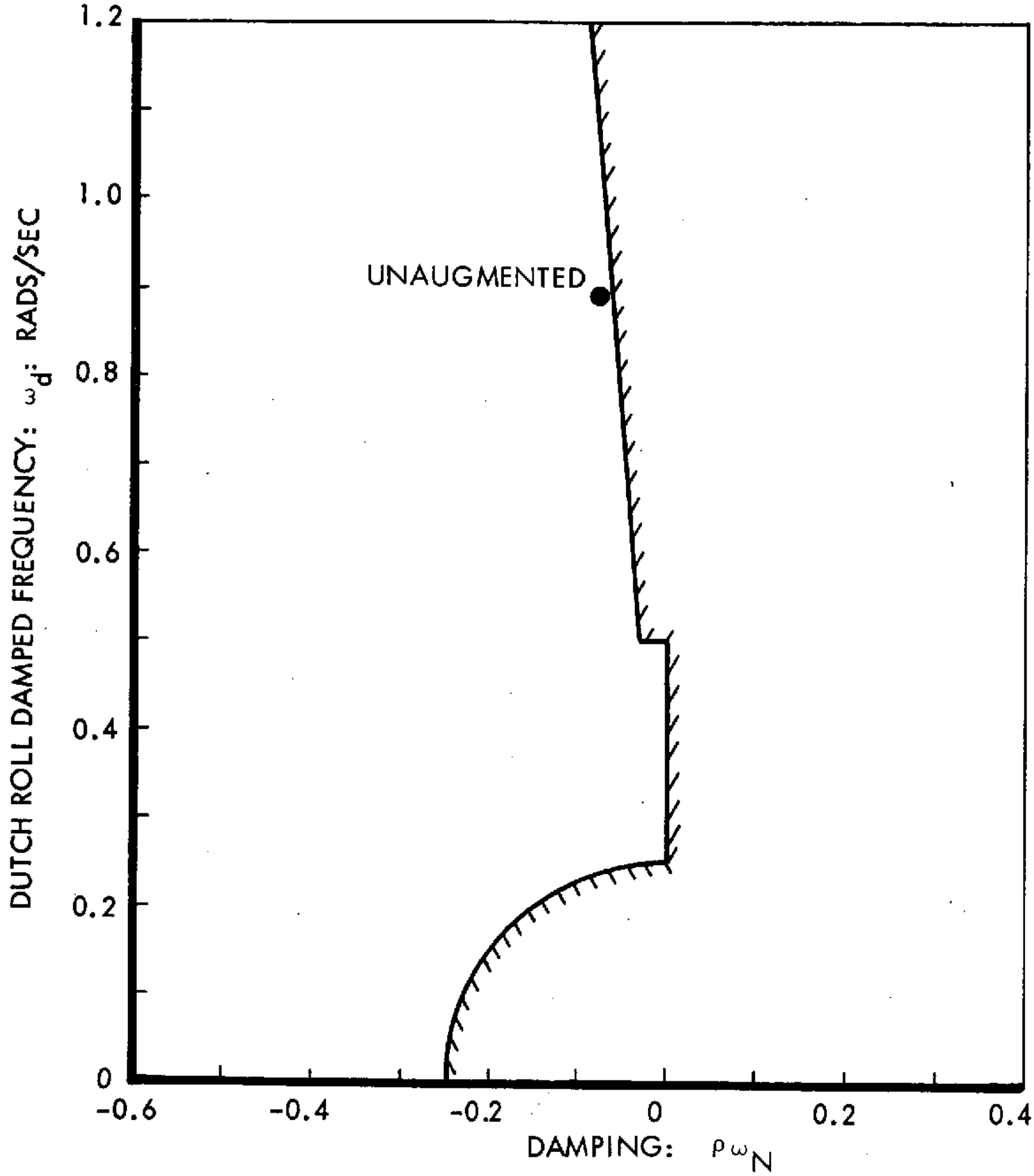

FIGURE 251 LATERAL DIRECTIONAL REQUIREMENTS (MF)

(9.8 ft./sec.) for the landing approach case of 176 km/hr. (95.4 knots) at 152m. (500 ft.) were used. The results are compared with the specified criteria in Figure 252 for the longitudinal mode and Figure 253 for the lateral-directional mode. The critical condition is the magnitude of the RMS acceleration for the landing approach condition in the longitudinal mode. The accelerations for the descent case are almost as critical and even the cruise phase of flight exceeds the criteria.

The deterioration of ride quality from that shown in Ref. 2 studies is due primarily to the lower wing loading of this particular vehicle. Previous mechanical flap configurations had wing loadings of approximately 410 Kg/m.^{2} (85 lb./sq.ft.) at a field length of 1219m. (4000 ft.) while the new configuration wing loading is in the vicinity of 280 Kg/m.^{2} (58 lb./sq.ft.) at the shorter 914m. (3000 ft.) field length. Hence, an effects study was conducted to identify the equivalent condition which would have to be satisfied by a ride control system to provide a level of ride comfort to meeting the specified criteria. Since these criteria are debatable at present, the characteristics have also been related to those of existing transports in a similar analysis. The transport chosen was the CV-880 because of the availability of published aerodynamic characteristics in Reference 35.

It has been shown that the RMS level of vertical acceleration (σ g) varies inversely with wing loading (W/S) and directly with lift curve slope (C_L) and speed. The estimated variation of σ g with individual changes in W/S, C_L and descent speed at 3050 m. (10,000 ft.) for this vehicle is presented in Figure 254 and compared with the nominal limits of acceptability. These curves make it obvious that obtaining the desired ride quality by speed reduction alone is impractical from an operational point of view and that an equivalent increase in wing loading cannot be reconciled with the landing field performance required. The "natural" C_L value of the MF is already relatively low and from a design point of view reducing the accelerations by this alone would be impractical. Hence, the "effective" C_L will have to be drastically reduced by a ride control system.

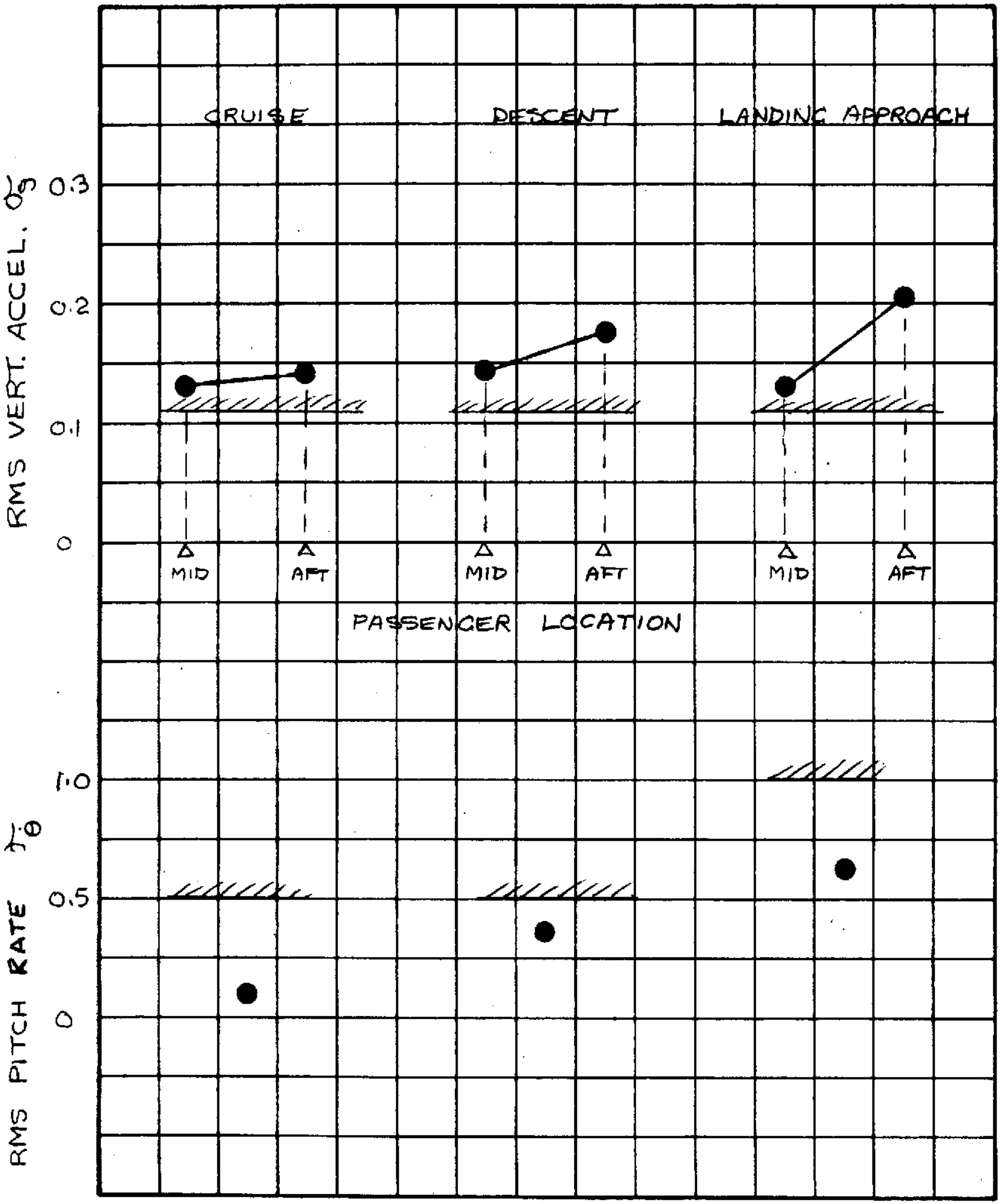

FIGURE 252 LONGITUDINAL RIDE QUALITIES (MF)

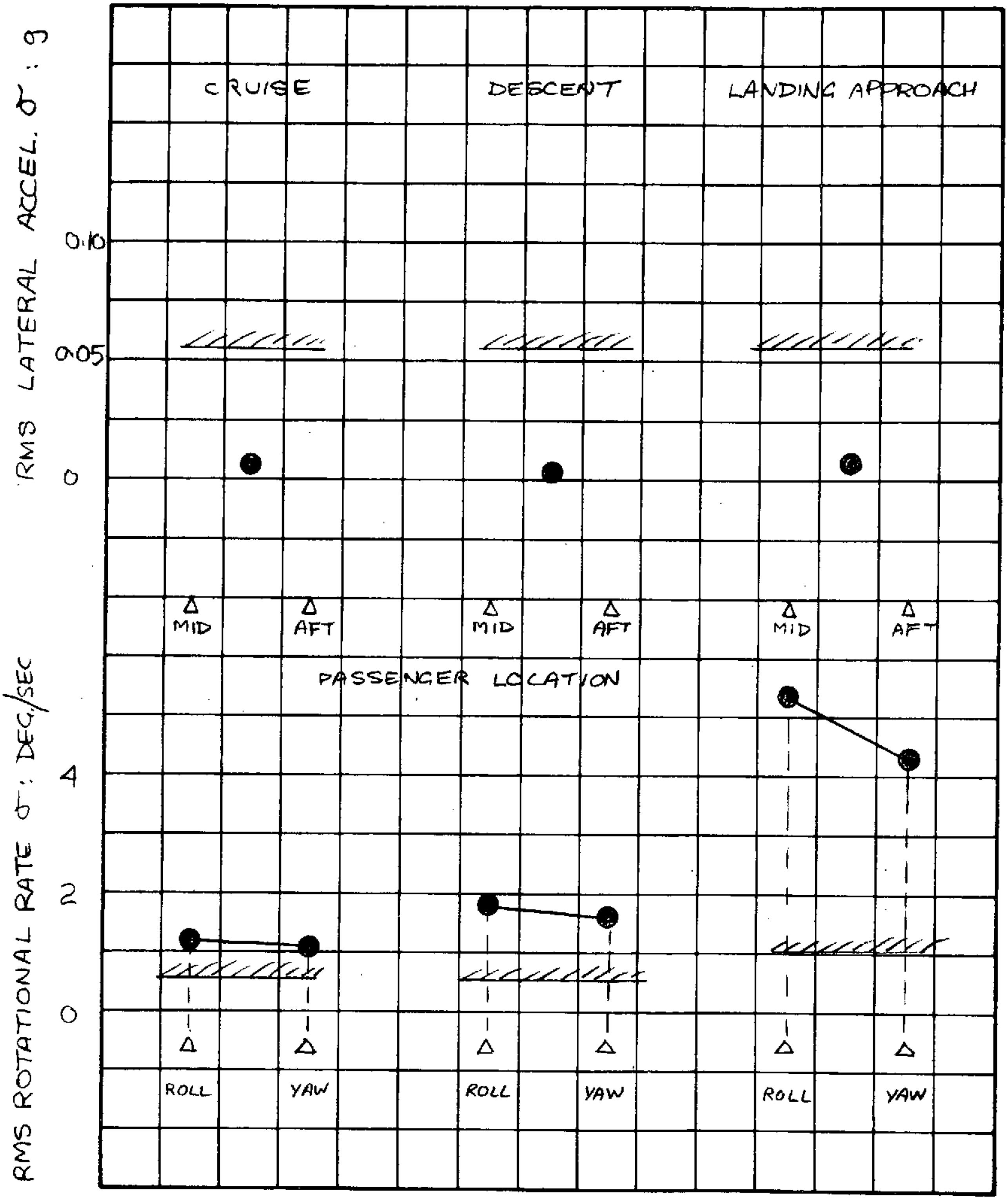

FIGURE 253 LATERAL RIDE QUALITIES (MF)

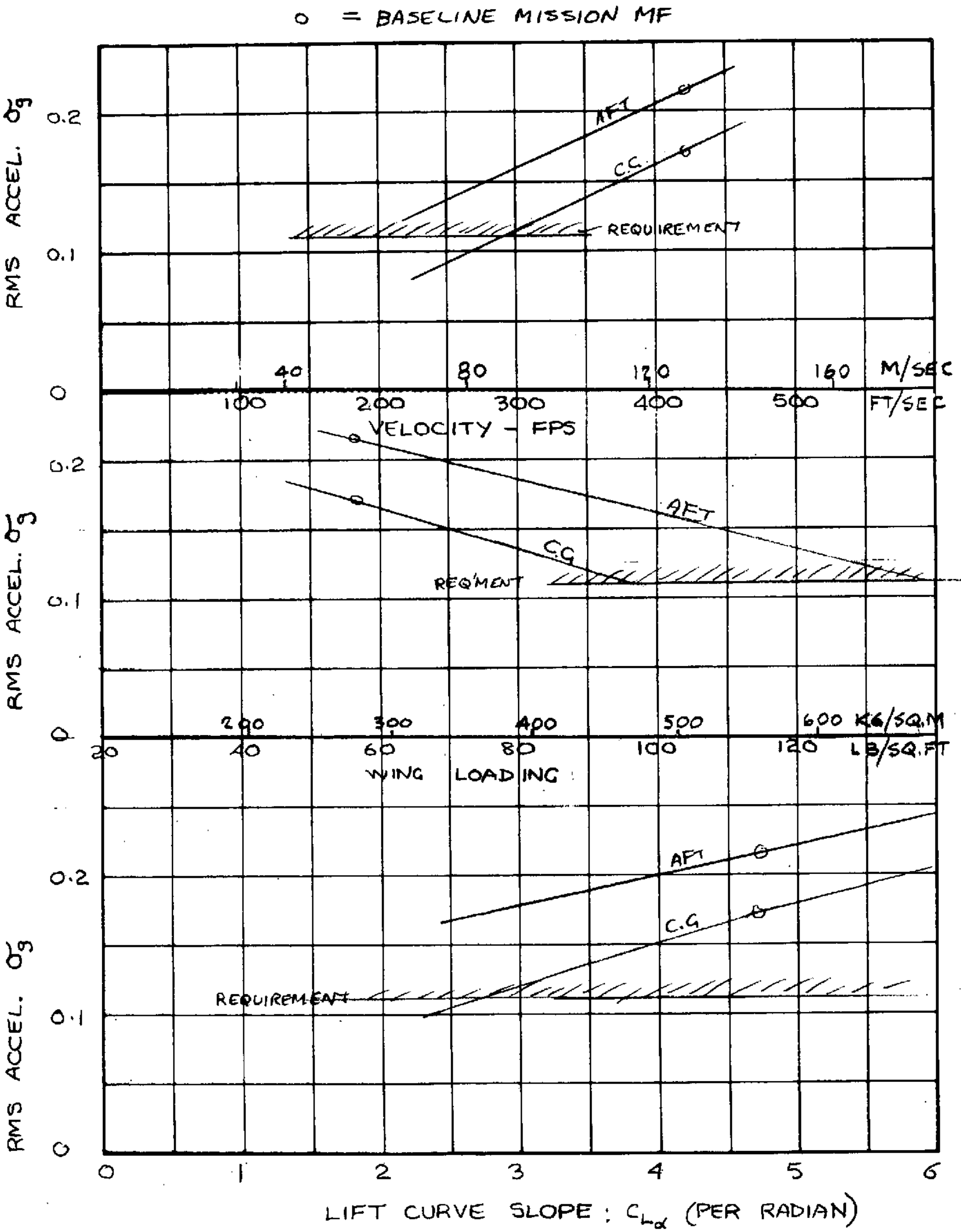

FIGURE 254 VARIATION OF RIDE QUALITY PARAMETERS

The pitch rate and the lateral accelerations are well within acceptable limits but the roll and yaw angular accelerations exceed the prescribed rates. However, these criteria are believed to be too stringent (as discussed in Reference 2) and the rates for this configuration are less than those estimated for the CV-880.

It has been concluded that a ride quality control system to effectively reduce the C_L is required to give this design acceptable characteristics. The lateral-directional mode (although it exceeds criteria) would probably be helped by a longitudinal system and would be acceptable. These results are based on an analysis of rigid body and unaugmented stability characteristics. A stability augmentation system would be required as already discussed and such a system would improve the ride qualities even without a ride control system per se.

The baseline vehicle has an aspect ratio of 7 whereas the fuel conservative MF vehicles described in Section 6.5 have higher aspect ratios between 10 and 14 and correspondingly higher lift curve slopes. At the same design field length, these vehicles will be equally landing critical and hence will have substantially similar wing loadings. However, their gust sensitivities will be higher and the RMS accelerations at the C.G. will be between 7% and 15% higher than the baseline vehicle. At field lengths of 1220m. (4000 ft.) or greater, the associated higher wing loadings more than compensate for this effect and it can be shown that the absolute minimum mission-fuel configurations with field lengths of the order of 1830m. (6000 ft.) may well satisfy the stated ride quality criteria without augmentation. Thus the preceding discussion of the baseline vehicle and the conclusions drawn may be taken to apply to the fuel conservative vehicles in principle but in differing degree.

6.7 MF WEIGHT AND BALANCE

The MF configuration weight data were computed by a modified version of the computer program used in the Ref. 2 study. The modifications resulted from analyses conducted to:

- Improve the flap and nacelle weight estimates.
- Determine the effects of the low wing loading required for short-field performance.
- Determine the effects of the higher aspect ratios required by the fuel conservative designs.

This section summarizes the studies conducted to quantify these effects. Group weight statements are not included in this section, but are contained in the individual airplane sections.

6.7.1 MF Flap Weight

Analyses were conducted to develop the equation presented in Figure 128 which is contained in Section 4.8.1. This equation computes the weight of the trailing edge flap and accounts for such parameters as design landing weight, wing area, flap area, flap design speed, wing thickness to chord ratio and the type of flap. Factors were determined for plain, hinged, Fowler, and slotted versions of each of these types. Correlation of actual flap weights of a number of contemporary aircraft, including the Breguet 941 STOL airplane, is shown to be very good in Figure 128.

6.7.2 MF Wing Weight

The total wing weight for this concept followed the procedure described in Section 4.8.1. This consists of subtracting from the basic statistical wing weight equation, computed values of a conventional Fowler flap, secondary structure and aileron to obtain a value for the wing box weight and then adding computed values for the flap, secondary structure and ailerons for this particular concept. Finally, the wing weight was adjusted for the incremental weight caused by the low-wing loading required for the short field lengths, as applicable. These secondary effects of low-wing loading and the possible weight increments attributable to high aspect ratio have been investigated in some detail and are reported in the following sections.

Low-Wing Loading - The MF configurations sized for 910m (3000 ft.) field performance have a wing loading of 287 Kg/m^2 (58.8 lb/sq ft). Structural analyses were conducted to evaluate the effects on wing weight of possible gust, aeroelastic and fatigue problems at this unusually low wing loading. The gust load factor for this wing loading and the aerodynamic characteristics of the AR7.0 wing is presented in Figure 255 as a function of cruise speed for the gross weight and minimum fuel weight of a typical 910m (3000 ft.) field length MF airplane.

For the 0.8M designs, a dive speed of 760 Km/hr (410 knots) EAS is required which results in a limit gust load factor of 4.05 for the minimum fuel weight case, as shown in the figure. Six wings of identical geometry but with different combinations of limit load factor, allowable fatigue stress, and aeroelastic consideration were analyzed by the wing multiple station analysis program. The resulting wing box weights are shown in Table XXIX. Wing #6 is the final wing meeting all the structural requirements. Because of the increase in size of the structural members to meet the aeroelastic requirements, the gust effects are not critical and a gust alleviation system is not required from the structural viewpoint. As an example of the analyses conducted, Figure 256 which shows the multiple station analysis printout for the final wing box (#6), is included. Each individual wing weight at this low wing loading was then adjusted to reflect the increment obtained from this analysis relative to the wing weight obtained by the procedure described in Section 4.8.1.

High Aspect Ratio Wing - A mechanical flap concept wing with 10° sweep, 0.7 cruise Mach number and 77.8m^2 (837 sq. ft.) was analyzed with aspect ratios of 7, 9, 12, and 14 using the Lockheed Wing Multiple-Station Analysis computer program, and a typical set of output data is presented in Figure 256. The program was initially

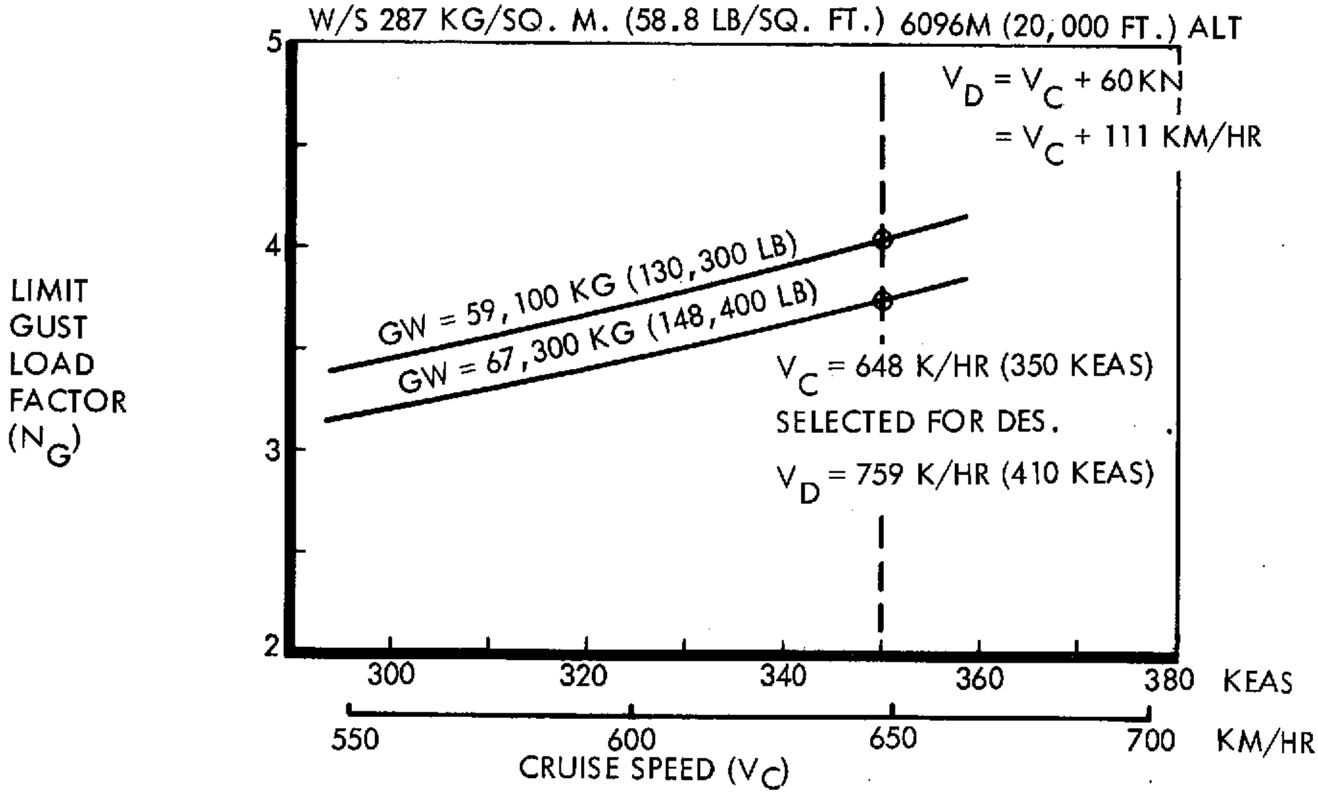

FIGURE 255 MF - GUST LOAD FACTOR AT LOW WING LOADING

W/S = 58.8 LB/SQ. FT. (287 KG/SQ. M)

WING NO.	1	2	3	4	5	6
LIMIT LOAD FACTOR	2.5	2.5	4.05*	4.05*	4.05*	4.05*
ALLOW. FATIGUE STRESS KSI (KN/SQ.M)	81 (26.9)	55 (18.3)	55 (18.3)	45 (15.0)	40 (13.3)	40 (13.3)
AEROELASTIC EFFECTS CONSIDERED	NO	NO	NO	NO	NO	YES
WING BOX WT. LB (KG)	6239 (2830)	6418 (2911)	8694 (3944)	8800 (3992)	8844 (4012)	11868 (5383)

WING BOX AREA = 968 FT^2 ($90M^2$)

WING AREA = 2511 FT^2 ($233M^2$)

SECONDARY STRUCTURE - LB. (KG) 3028 (1374)

CONTROL SURFACES - LB. (KG) 9274 (4207)

TOTAL WING WEIGHT - LB. (KG) 24170 (10960)

* GUST LOAD FACTOR AT MINIMUM FUEL WEIGHT

TABLE XXIX: MF - WING WEIGHT FOR LOW WING LOADING

```
NASS MECH FLAP CONFIG(GUST LOADS - VC=350KEAS)40KSI FAT; GJ=.9EI
ESTIMATED LOAD DISTRIBUTION IN EA CO-OR
 LOAD CASE  1      PZ           MXP          MYP          TAXI-2G
   ETAI
   .9500      -.1368+04    -.2429+05     .1467+04
   .8500      -.5562+04    -.2981+06     .7063+04
   .7500      -.1161+05    -.9764+06     .9510+04
   .6500      -.2005+05    -.2498+07     .2971+05
   .5500      -.3078+05    -.4431+07     .7293+05
   .4500      -.3555+05    -.7125+07     .9716+05
   .3585      -.3648+05    -.9823+07     .1587+06
   .2585      -.5956+05    -.1376+08    -.4831+06
   .1390      -.7476+05    -.2035+08    -.3819+06
   .0390      -.9312+05    -.262[illegible]+08     .7321+07
 LOAD CASE  2      PZ           MXP          MYP          2.5G MAN.-CRUISE
   ETAI
   .9500       .2776+04     .4073+05     .7156+05
   .8500       .8161+04     .4241+06     .2614+06
   .7500       .1407+05     .1267+07     .5330+06
   .6500       .2755+05     .2879+07     .8924+06
   .5500       .4218+05     .5619+07     .1396+07
   .4500       .5800+05     .9596+07     .2014+07
   .3585       .7319+05     .1440+08     .2684+07
   .2585       .6713+05     .2011+08     .265[illegible]+07
   .1390       .8919+05     .2753+08     .384[illegible]+07
   .0390       .9780+05     .3470+08    -.4985+07
 LOAD CASE  3      PZ           MXP          MYP          2G T.O.
   ETAI
   .9500       .2185+04     .3202+05     .5670+05
   .8500       .6462+04     .3[illegible]8+06     .2081+06
   .7500       .1128+05     .1004+07     .4273+06
   .6500       .2[illegible]40+05     .2365+07     .5341+06
   .5500       .3469+05     .4745+07     .5231+06
   .4500       .4804+05     .8204+07     .4955+06
   .3585       .6104+05     .1238+08     .4627+06
   .2585       .5677+05     .1743+08    -.329[illegible]+06
   .1390       .7518+05     .2397+08    -.1718+06
   .0390       .8258+05     .2893+08    -.8065+07
 LOAD CASE  4      PZ           MXP          MYP          2G LANDING
   ETAI
   .9500       .1979+04     .2960+05     .5085+05
   .8500       .5770+04     .3013+06     .1835+06
   .7500       .1448+05     .1061+07     .3600+06
   .6500       .2493+05     .2678+07     .4211+06
   .5500       .3650+05     .5275+07     .3051+06
   .4500       .4904+05     .8[illegible]94+07     .1504+06
   .3585       .6124+05     .1317+08    -.3065+06
   .2585       .5601+05     .1825+08    -.1016+07
   .1390       .7318+05     .2473+08    -.1070+07
   .0390       .8396+05     .2941+08    -.9308+07
 LOAD CASE  5      PZ           MXP          MYP          GUST-RES FUEL 350K
   ETAI
   .9500       .5159+04     .7655+05     .98[illegible]+05
   .8500       .1763+05     .8935+06     .356[illegible]+06
   .7500       .3[illegible]82+05     .2899+07     .7349+06
   .6500       .5219+05     .6304+07     .1273+07
   .5500       .72[illegible]+05     .1126+08     .19[illegible]5+07
   .4500       .9402+05     .1790+08     .28[illegible]+07
   .3585       .1154+06     .25[illegible]9+08     .3861+07
   .2585       .1012+06     .3441+08     .3675+07
   .1390       .1320+06     .4549+08     .5424+07
   .0390       .1595+06     .5648+08    -.9379+07
 LOAD CASE  6      PZ           MXP          MYP          GUST-CROSS WT 350K
   ETAI
   .9500       .4189+04     .6149+05     .1077+06
   .8500       .1230+05     .6402+06     .3929+06
   .7500       .2114+05     .1909+07     .8012+06
   .6500       .4131+05     .4329+07     .13[illegible]8+07
   .5500       .6318+05     .8436+07     .2091+07
   .4500       .8683+05     .1439+08     .3017+07
   .3585       .1093+06     .2158+08     .4020+07
   .2585       .1005+06     .3012+08     .3976+07
   .1390       .1356+06     .4123+08     .5768+07
   .0390       .1466+05     .5198+08    -.7459+07
```

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FIGURE 256 (1) WING MULTIPLE STATION ANALYSIS: COMPUTER OUTPUT

ETAI	.9500	.8500	.7500	.6500	.5500	.4500	.3585	.2585	.1390	.3900-01
RIB SPACING	24.30	24.30	24.30	24.30	24.30	24.30	24.30	27.00	27.00	31.00
BEND STIFF	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
AFT CELL -UP										
TBAR	.1061	.1044	.1175	.1483	.1761	.1940	.2087	.2259	.2400	.2493
TSKIN	.8840-01	.8699-01	.9326-01	.1178	.1407	.1536	.1637	.1752	.1815	.1823
TBAR/TSKIN	1.200	1.200	1.260	1.260	1.251	1.263	1.275	1.290	1.274	1.367
RHOE EQUIV	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010
RISER PITCH	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
DEL WT-FAT	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
DEL WT-TOR	.4169-02	.3237-02	.2385-02	.3311-02	.4008-02	.3811-02	.3198-02	.3161-02	.3470-02	.2797-02
TWEB/TSKIN	.2500	.2500	.3248	.3245	.3141	.3289	.3437	.3623	.3419	.4593
BWEB/PITCH	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000
TSKTOR	.8840-01	.8699-01	.9326-01	.1178	.1407	.1536	.1637	.1752	.1815	.1823
TYPE CONST	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
CRIT COMP	5.000	5.000	500.0	500.0	500.0	500.0	500.0	500.0	500.0	500.0
CRIT TEN	100.0	100.0	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
AFT CELL -LO										
TBAR	.1061	.1044	.1179	.1413	.1688	.1843	.2090	.2397	.2607	.2919
TSKIN	.8840-01	.8699-01	.9326-01	.1178	.1407	.1536	.1637	.1752	.1815	.1823
TBAR/TSKIN	1.200	1.200	1.200	1.200	1.200	1.200	1.277	1.369	1.415	1.601
RHOE EQUIV	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010
RISER PITCH	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
DEL WT-FAT	.0000	.0000	.0000	.0000	.0000	.0000	.1274-02	.2983-02	.4095-02	.7387-02
DEL WT-TOR	.4169-02	.3908-02	.4430-02	.1987-02	.2139-03	.6188-03	.1837-02	.1760-02	.1514-02	.0000
TWEB/TSKIN	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500	.2500
BWEB/PITCH	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000	.5000
TSKTOR	.8840-01	.8699-01	.9326-01	.1178	.1407	.1536	.1637	.1752	.1815	.1823
TYPE CONST	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00	21.00
CRIT COMP	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
CRIT TEN	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0	600.0
FRONT BEAM										
DWFAT-UP	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
DWFAT-LO	.0000	.9058-02	.4791-02	.2862-01	.1549-01	.2594-01	.3974-01	.1005	.1192	.3727-01
AREA -UP	.7500-01	.5487	.4953	1.066	1.190	1.249	.7582	1.637	1.966	4.054
AREA -LO	.7500-01	.2116	.1375	.6145	.4665	.6725	.9107	1.967	2.362	1.432
DWTOR	.7789-02	.1387-01	.1428-01	.1956-01	.2184-01	.2563-01	.2545-01	.2750-01	.3074-01	.3309-01
TWEB	.8840-01	.8699-01	.9326-01	.1178	.1407	.1536	.1637	.1752	.1815	.1823
ALPHA T	1.257	1.407	1.600	1.606	1.724	1.790	1.842	1.506	1.599	1.551
RHO EQUIV	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010
HEIGHT WEB	11.86	15.16	18.43	21.69	24.98	28.20	31.17	34.42	38.29	40.27
REAR BEAM										
DWFAT-UP	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
DWFAT-LO	.0000	.4763-02	.1655-01	.3061-01	.0000	.5374-01	.7289-01	.1052	.1250	.0000
AREA -UP	.7500-01	.1017	.2698	.4986	1.241	1.049	1.291	1.715	2.037	3.778
AREA -LO	.7500-01	.1277	.3280	.5989	.7510	1.051	1.426	2.059	2.416	1.781
DWTOR	.8318-02	.7956-02	.1049-01	.1582-01	.2456-01	.2626-01	.2871-01	.3262-01	.2839-01	.3113-01
TWEB	.8840-01	.8699-01	.9326-01	.1178	.1407	.1536	.1637	.1752	.1815	.1823
ALPHA T	1.257	1.206	1.294	1.301	1.543	1.593	1.631	1.608	1.279	1.735
RHO EQUIV	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010	.1010
HEIGHT WEB	12.05	15.52	18.99	22.46	25.92	29.39	32.57	36.04	40.18	42.30
RIB AFT CELL										
CAP AREA-UP	.7500-01	.7500-01	.7500-01	.7500-01	.8153-01	.1164	.1462	.3971	.1738	.1645
CAP AREA-LO	.7500-01	.7500-01	.7500-01	.7500-01	.8601-01	.1153	.1400	.1357	.1459	.1468
DWFAT-UP	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.0000
DWFAT-LO	.0000	.0000	.0000	.0000	.0000	.0000	.0000	.2312-01	.0000	.0000
TWEB	.2039-01	.2039-01	.2039-01	.2039-01	.2039-01	.2039-01	.2134-01	.2363-01	.2630-01	.2763-01
ALPHA T	1.022	1.209	1.627	2.306	3.271	4.109	4.390	3.537	4.040	1.013
HEIGHT WEB	12.11	15.47	18.83	22.20	25.57	28.95	32.01	35.45	39.49	41.44

FIGURE 256 (2) WING MULTIPLE STATION ANALYSIS: COMPUTER OUTPUT

		CENTER WING	INNER WING	OUTER WING	TOTAL WING
1	UPPER-FRONT -SPAR CAP	76.	0.	230.	306.
2	UPPER-CENTER-SPAR CAP	0.	0.	0.	0.
3	UPPER-REAR -SPAR CAP	71.	0.	212.	283.
4	UPPER-INTERSPAR COVER	341.	0.	2129.	2469.
5	UPPER-SPANWISE STIFF.	125.	0.	567.	692.
6	UPPER-JTS.,SPL.,FAST.	23.	0.	133.	156.
7	UPPER-FUSE. JOINT -INCR.	188.	0.	172.	360.
8	UPPER-BREAK JOINT -INCR.	0.	0.	0.	0.
9	LOWER-FRONT -SPAR CAP	36.	0.	259.	295.
10	LOWER-CENTER-SPAR CAP	0.	0.	0.	0.
11	LOWER-REAR -SPAR CAP	45.	0.	305.	350.
12	LOWER-INTERSPAR COVER	326.	0.	2008.	2334.
13	LOWER-SPANWISE STIFF.	196.	0.	597.	793.
14	LOWER-JTS.,SPL.,FAST.	26.	0.	130.	156.
15	LOWER-FUSE. JOINT -INCR.	210.	0.	183.	393.
16	LOWER-BREAK JOINT -INCR.	0.	0.	0.	0.
17	SPAR WEB + STIFF.-FRONT	114.	0.	723.	837.
18	SPAR WEB + STIFF.-CENTER	0.	0.	0.	0.
19	SPAR WEB + STIFF.-REAR	134.	0.	670.	804.
20	INTERSPAR RIBS	100.	0.	1540.	1641.
21	(SUB-TOTAL WING BOX)	(2011.)(	0.)(	9855.)(	11869.)
22	FIXED LEADING EDGE	0.	0.	1584.	1584.
23	FIXED TRAILNG EDGE	0.	0.	278.	278.
24	TIPS	0.	0.	30.	30.
25	TOTAL-BASIC STRUCTURE	2011.	0.	11750.	13760.

CASE 2 NASS MECH FLAP CONFIG(GUST LOADS - VC=350KEAS)40KSI FAT, GJ=.9EI

WING WEIGHT SUMMARY

BASIC STRUCTURE			13760.
CENTER WING		2011.	
OUTER WING		11750.	
DOORS, PANELS, AND MISC.			1135.
ACCESS DOORS - UPR. SURF		75.	
WING-FUSE. FAIRING		893.	
PAINT AND MISC.		168.	
CONTROL SURFACES			9274.
AILERONS		1277.	
STRUCTURE	638.		
BALANCE WTS ,HINGES,SPTS	638.		
TRAILNG EDGE FLAPS		5597.	
LEADING EDGE FLAPS		1592.	
SPOILERS		807.	
TOTAL-WING WEIGHT			24170.

WT PENALTIES INC FOR TORSIONAL

AND BEND STIFF AND FAT

ETAI	TOR STIFF	BEND STIFF	FATIGUE
.95000	38.840	.00000	.00000
.85000	54.821	.00000	1.0994
.75000	65.640	.00000	1.6984
.65000	92.817	.00000	4.7118
.55000	123.89	.00000	1.2324
.45000	151.59	.00000	6.3.77
.35850	148.19	.00000	16.005
.25850	248.60	.00000	52.322
.13900	284.69	.00000	72.801
.03900	182.85	.00000	61.705
TOTAL-A/C	2786.0	.00000	435.83

STIFFNESS DISTR FOR LAST CYCLE

ETAI	EI	GJ
.95000	.44388+10	.38700+10
.85000	.90807+10	.75600+10
.75000	.17423+11	.1415 +11
.65000	.36538+11	.20600+11
.55000	.65261+11	.51300+11
.45000	.10167+12	.80100+11
.35850	.14918+12	.11430+12
.25850	.23032+12	.16425+12
.13900	.34356+12	.24210+12
.03900	.44810+12	.28000+12

WING EXTERNAL GEOMETRY

DIMENSIONAL DATA

GROSS AREA	(SQ FT)	2511.0
EXPOSED AREA	(SQ FT)	2217.9
EXPOSED WETTD AREA	(SQ FT)	4544.5
ASPECT RATIO		7.0000
SPAN	(FT)	132.58
SWEEP @ 25% CHORD -EQ	(DEGS)	20.000
THEO. ROOT CHORD	(IN)	349.60
MAX. ROOT THICKNESS	(IN)	52.903
THEO. TIP CHORD	(IN)	104.90
MAX. TIP THICKNESS	(IN)	12.126
MEAN AERO CHORD	(IN)	249.24
LEMAC (FUSE STA)	(IN)	653.80
LAT POSITION OF MAC (BL)	(IN)	326.35
TAIL LENGTH WG TO HT	(IN)	850.00

FIGURE 256 (3) WING MULTIPLE STATION ANALYSIS: COMPUTER OUTPUT

cycled for each of the four aspect ratios to obtain wing weights and stiffness distribution data for "strength-designed" wings. From flutter studies of a similar wing with a flutter speed of 917 Km/hr (495 K) EAS, a GJ/EI (torsional stiffness to bending stiffness) ratio of 0.90 was determined to be required whereas a value of approximately 0.30 was achieved by the "strength-designed" wings. The station analysis computer program was then re-cycled to account for the increased ratio GJ/EI which was demanded.

The results of these computations are presented in Table XXX and compared with wing weights computed from the parametric equations used in the airplane sizing program. The table shows the wing weight calculated for the "strength-designed" wings and the additional structural weight required to meet the stiffness criteria (GJ/EI = 0.9). The differences between the "stiffness-designed" weights and the parametric weights are such that, for aspect ratio 12 or less, the parametric weight is up to 4% too heavy, while at aspect ratio 14, it is 4% too light. These conclusions are regarded as sufficient validation of the parametric methodology for high aspect ratio wing weight prediction.

6.7.2 MF Nacelle Weight

Based on the nacelle descriptions shown in Figures 6.5 and 6.6 detailed weight estimates have been calculated for the 1.35 and 1.574 FPR nacelles. These estimates were based on C-5A component weights, NASA QUESTOL and DDA QCSEE data, and computed individual component weights for the inlet cowl, fan case cowl, thrust reverser, core cowl, primary exhaust system, and variable fan nozzle and controls. Advanced composite construction was then assumed and the estimated weights reduced by 15%. The base nacelle weights for the 1.35 FPR engine are presented in Table XXXI and compared with the equivalent OTW/IBF installation. It will be noted that the OTW/IBF installation is only slightly heavier than the MF nacelle and pylon combination. Whereas, the surface area and weight of the nacelle per se are substantially greater for the over-wing installation, the weight differential is almost completely recouped by the savings from the simpler thrust reversing provisions and the elimination of the inherently heavy (stiffness critical) pylon.

MF: 0.7M; WING AREA = 77.8 SQ. M. (837 SQ. FT.); 2-ENGINE

ASPECT RATIO	WING MULTI-STATION ANALYSIS			PARAMETRIC VALUE
	STRENGTH DESIGN	STIFFNESS PENALTY	STIFFNESS DESIGN	
14	3905 (8610)	+887 (+1956)	4793 (10,566)	4593 (10,125)
12	3537 (7797)	+724 (+1596)	4261 (9,393)	4277 (9,429)
9	3181 (7012)	+403 (+ 889)	3584 (7,901)	3745 (8,257)
7	2932 (6464)	+296 (+ 653)	3228 (7,117)	3337 (7,356)
	KG (LB)	KG (LB)	KG (LB)	KG (LB)

TABLE XXX: WEIGHT EFFECTS OF ASPECT RATIO

UNINSTALLED RATED THRUST = 128 KN (28,800 LB.) FPR 1.35

CONCEPT	WEIGHT - KG (LB.)	
	MF	OTW/IBF
INLET ASSEMBLY	180 (397)	208 (459)
FAN CASE COWL	92 (202)	50 (110)
FAN DUCT DOORS	-	275 (607)
UPPER FAN DUCT	-	92 (203)
CORE COWL	180 (397)	209 (461)
FAN EXHAUST NOZZLE	-	174 (384)
PRIMARY EXHAUST	42 (93)	164 (362)
ENGINE MOUNTS	39 (86)	39 (87)
FRAMES, LONGERONS, ETC.	-	214 (472)
CONVENTIONAL NACELLE	533 (1175)	1427 (3145)
COMPOSITE NACELLE (CONV. X .85)	453 (999)	1212 (2673)
THRUST REVERSER SYSTEM	457 (1008)	194 (427)
PYLON	449 (990)	0 (0)
TOTAL (INCL. COMP. NAC.)	1359 (2997)	1406 (3100)

TABLE XXXI: OTW/IBF - COMPARISON WITH MF NACELLE WEIGHTS

6.8 NOISE ANALYSES

The engines used in mechanical flap aircraft design and noise analyses were the same as those used on the OTW/IBF aircraft. The methods of analysis were those described in Section 4.9.

6.8.1 Engine Noise Characteristics

Wall treatment in an aerodynamic nacelle was the only noise attenuation applied in contrast to the heavily noise treated engines of Reference 2, Section 2.2.2.6. As a consequence, suppressed fan noise in the current study was approximately 4 dB above that of the same engines. Installed engine performance was correspondingly better in the current study .) Typical component noise levels are presented in Table XXXII. A significant difference from the hybrid OTW/IBF levels (Table VIII) is in the higher level of aft noise for the 1.25 and 1.35 FPR engines as a consequence of the short nacelle without fan duct treatment (compared to the long exhaust duct for the OTW/IBF and the wing shielding effect of the upper surface engine location). Because of the criticality of aft noise it was concluded that splitters or other additional inlet treatment would be ineffective and uneconomical because the performance loss would be increased considerably without significant improvement in noise.

6.8.2 Aircraft Design and Noise Data

Aircraft characteristics are summarized in Table XXXIII. Noise levels and footprint areas are shown in Table XXXIV. Computer printouts of the design characteristics are reproduced in the appendices.

Sideline and flyover noise levels for takeoff are shown in Figure 257 as a function of field length for the two-engine aircraft with FPR 1.35 engines. Footprint areas are shown in Figure 258 and footprint lengths are plotted in Figures 259 and 260. Approach footprint areas and lengths were lower than takeoff footprint areas.

The effect of engine fan pressure ratio on takeoff noise of 4-engine aircraft designed for 1220 m. (4000 ft.) field lengths is shown in Figure 261 . The two engine aircraft

SINGLE ENGINE, SHIELDING AND EGA NOT INCLUDED. WALL TREATMENT ONLY.

	NOISE LEVEL (PNdB)					
	1.35 FPR		1.25 FPR		1.47 FPR	
	FWD	AFT	FWD	AFT	FWD	AFT
FAN, UNSUPPRESSED	100.8	103.6	96.5	101.2	106.1	
FAN, SUPPRESSED	96.5	96.7	92.5	93.9	102.1	
FAN JET	79.2	84.4	70.6	77.5	78.3	
PRI JET	57.1	62.3	55.4	62.1		
CORE	81.0	86.3	67.5	74.1	85.5	N/A
TURBINE	68.9	80.8	68.2	82.3	63.4	
AERO.	80.4	81.4	80.5	81.4	75.6	
TOTAL	100.7	102.1	96.5	99.1	108.7	
(NO. OF ENGINES)	2		2		4	
S.L.S. THRUST - LB.	35,412		42,000		9,757	
- KN	157.5		187		43.4	

TABLE XXXII: MF - COMPONENT NOISE SUMMARY AT MAXIMUM 152M (500 FT.) SIDELINE NOISE LOCATION

ENGINE FPR	1.35	1.35	1.35	1.35	1.35	1.25	1.47	1.35
NO. OF ENGINES	2	2	2	2	4	4	4	2
DES. FIELD LENGTH - m.	910	910	1220	1220	1220	1220	1220	1830
(FT.)	3000	3000	4000	4000	4000	4000	4000	6000
ASPECT RATIO	7.0	10.0	10.0	10.0	10.0	10.0	14.0	10.0
A/C OPTIMIZ BASIS	DOC (1)/(2)	DOC (4)/(10)	DOC (2)	DOC (1)	DOC (2)	DOC (2)	DOC (2)	DOC (2)
CR. ALT. - m.	9140	10,060	9140	9140	8230	7620	10,060	8230
(1000 FT.)	30	33	30	30	27	25	33	27
DES. CR. MACH NO.	0.75	0.70	0.75	0.80	0.75	0.65	0.75	0.75
RAMP GR. WT. - 1000 Kg	62.6	61.0	55.5	59.9	53.6	51.8	56.2	53.2
(1000 LB)	138.0	134.5	122.3	132.1	118.2	114.2	123.8	117.3
RATED THRUST - KN	127	117	107	119	46.7	46.4	43.4	90.3
(1000 LB)	28.54	26.29	23.97	26.78	10.49	10.44	9.76	20.30
T.O. W/S - Kg/m^2	278	282	393	391	403	403	403	454
psf	57.0	57.7	80.5	80.0	82.5	82.5	82.5	93.0
T/W INST.	0.379	0.355	0.359	0.375	0.325	0.323	0.292	0.317
T.O. FLAP - DEG.	13.5	21.5	24.0	16.3	25.0	29.0	33.0	2.5
DIST. TO 10.7 m (35 FT) - m.	719	719	954	969	1058	1059	1058	1521
(FT.)	2360	2360	3130	3179	3471	3475	3470	4989
VELOCITY - Kph	224	219	252	257	252	250	246	296
(KTS)	121	118	136	139	136	135	133	160
SEC. SEGM. CLB. - DEGREES	11.5	11.0	10.4	10.9	8.8	8.2	7.9	9.1
DIST. TO CUTBACK - m.	2243	2307	2645	2587	2459	2567	2595	3460
(FT.)	7360	7570	8677	8489	8069	8421	8514	11,351
CUTBACK POWER SETTING	0.78	0.75	0.79	0.79	0.59	0.63	0.59	0.72
CLB ANGLE AFTER CUTBACK	7.9	7.1	7.2	7.5	3.1	3.2	2.6	5.6
APPROACH ANGEL - DEG.	5.2	5.2	4.4	4.4	4.4	4.4	4.4	3.5
APP. POWER SETTING	0.33	0.26	0.31	0.34	0.38	0.38	0.33	0.13
APP. VEL. - Kph	181	182	216	216	216	216	216	273
(KTS)	97.9	98.5	116.6	116.6	116.6	116.6	116.6	147.2

TABLE XXXIII: MF AIRCRAFT FOR NOISE ANALYSIS

ENGINE FPR	1.35	1.35	1.35	1.35	1.35	1.25	1.47	1.35
NO. OF ENGINES	2	2	2	2	4	4	4	2
ASPECT RATIO	7.0	10.0	10.0	10.0	10.0	10.0	14.0	10.0
FIELD LENGTH - m.	910	910	1220	1220	1220	1220	1220	1830
(FT.)	3000	3000	4000	4000	4000	4000	4000	6000
SIDELINE NOISE								
EPNdB @ 152 m. (500')	98.0	97.8	96.5	96.9	95.6	106.3	104.8	95.0
305 m. (1000')	92.0	91.7	90.5	90.9	89.5	95.4	98.7	-
FAR 36 PT.	88.3	88.0	86.8	87.2	80.3	80.8	88.0	85.3
TAKEOFF FLYOVER								
EPNdB @ 1220 m. (4000')	102.1	102.2	106.1	106.5	109.9	106.3	119.7	104.4
@ 1830 m. (6000')	98.6	98.6	97.3	97.4	98.9	95.4	109.0	-
FAR 36 PT.	79.9	80.0	80.0	80.0	81.6	80.8	94.1	80.3
TAKEOFF AREAS								
SQ. Km @ 95 EPNdB	0.704	0.689	0.645	0.676	0.624	0.308	2.903	0.676
90 EPNdB	1.401	1.362	1.362	1.422	1.098	0.756	7.728	1.502
85 EPNdB	3.097	-	-	-	2.111	-	-	2.665
80 EPNdB	7.666	7.290	6.974	7.254	5.918	4.558	34.14	-
SQ. MI. @ 95 EPNdB	0.272	0.266	0.249	0.261	0.241	0.119	1.121	0.261
90 EPNdB	0.541	0.526	0.526	0.549	0.424	0.292	2.984	0.580
85 EPNdB	1.196	-	-	-	0.815	-	-	1.029
80 EPNdB	2.960	2.815	2.693	2.801	2.285	1.760	13.181	-
FOOTPRINT LENGTH								
m. @ 95 EPNdB	1984	1998	2134	2142	2359	1730	5779	2624
90 EPNdB	2212	2212	2540	2554	2338	2553	10,242	3456
80 EPNdB	6419	6483	6485	6504	8129	7297	22,620	-
FT. @ 95 EPNdB	6508	6556	7002	7029	7741	5675	18,894	8609
90 EPNdB	7258	7256	8332	8379	7671	8375	33,604	11,339
80 EPNdB	21,059	21,269	21,277	21,339	26,669	23,941	74,214	
APPROACH NOISE								
EPNdB @ 610 m. (2000')	97.2	-	96.4	-	-	95.6	102.8	93.5
1850 m. (1 N.MI.)	88.8	-	88.1	-	92.6	87.3	94.5	85.4
90 EPNdB AREA Km^2								
(SQ. MI.)	0.334	-	0.243	0.285	0.844	0.186	1.106	0.101
	0.129	-	0.094	0.110	0.326	0.072	0.427	0.039

TABLE XXXIV: SUMMARY OF MF NOISE

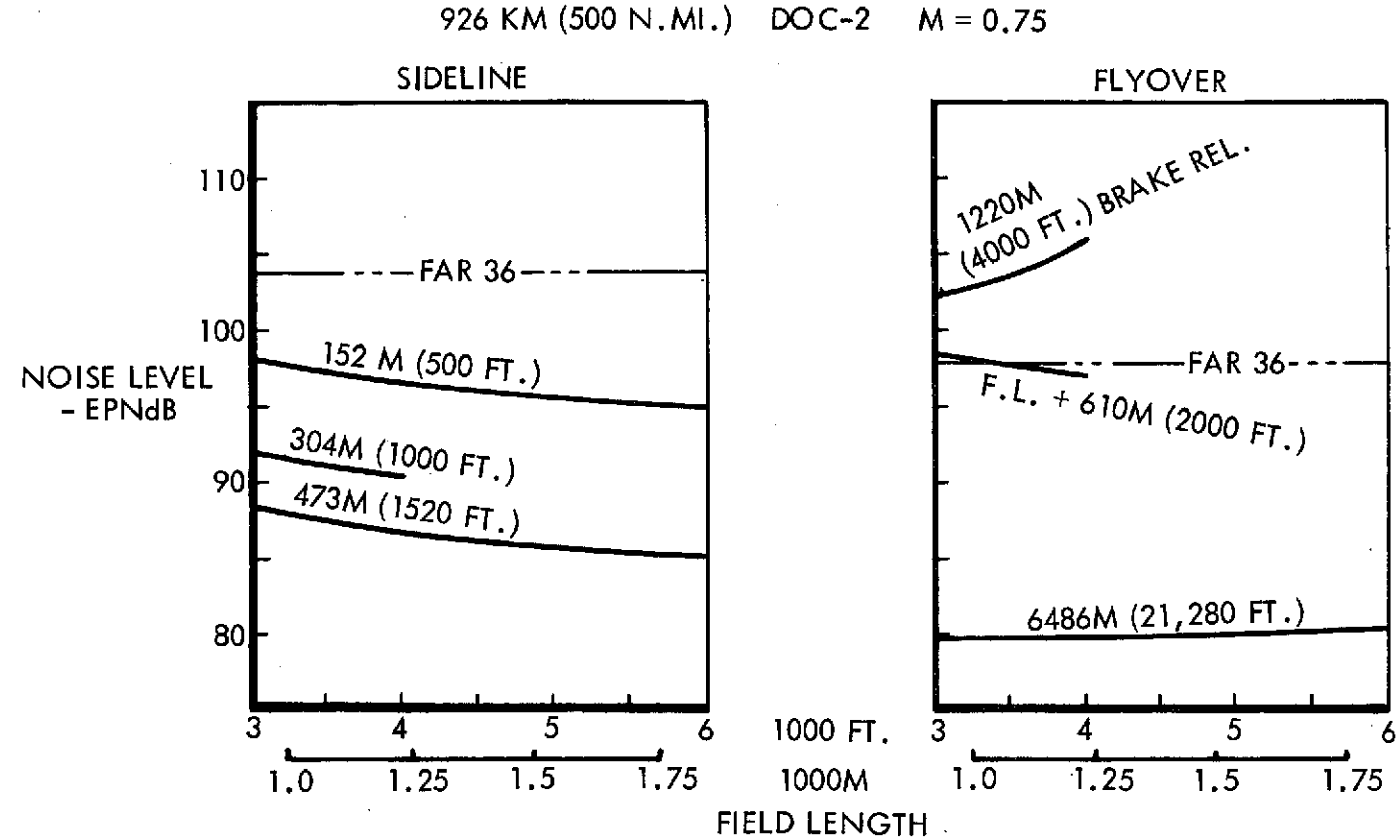


FIGURE 257 TAKEOFF NOISE LEVEL VS FIELD LENGTH (2-ENGINE MF)

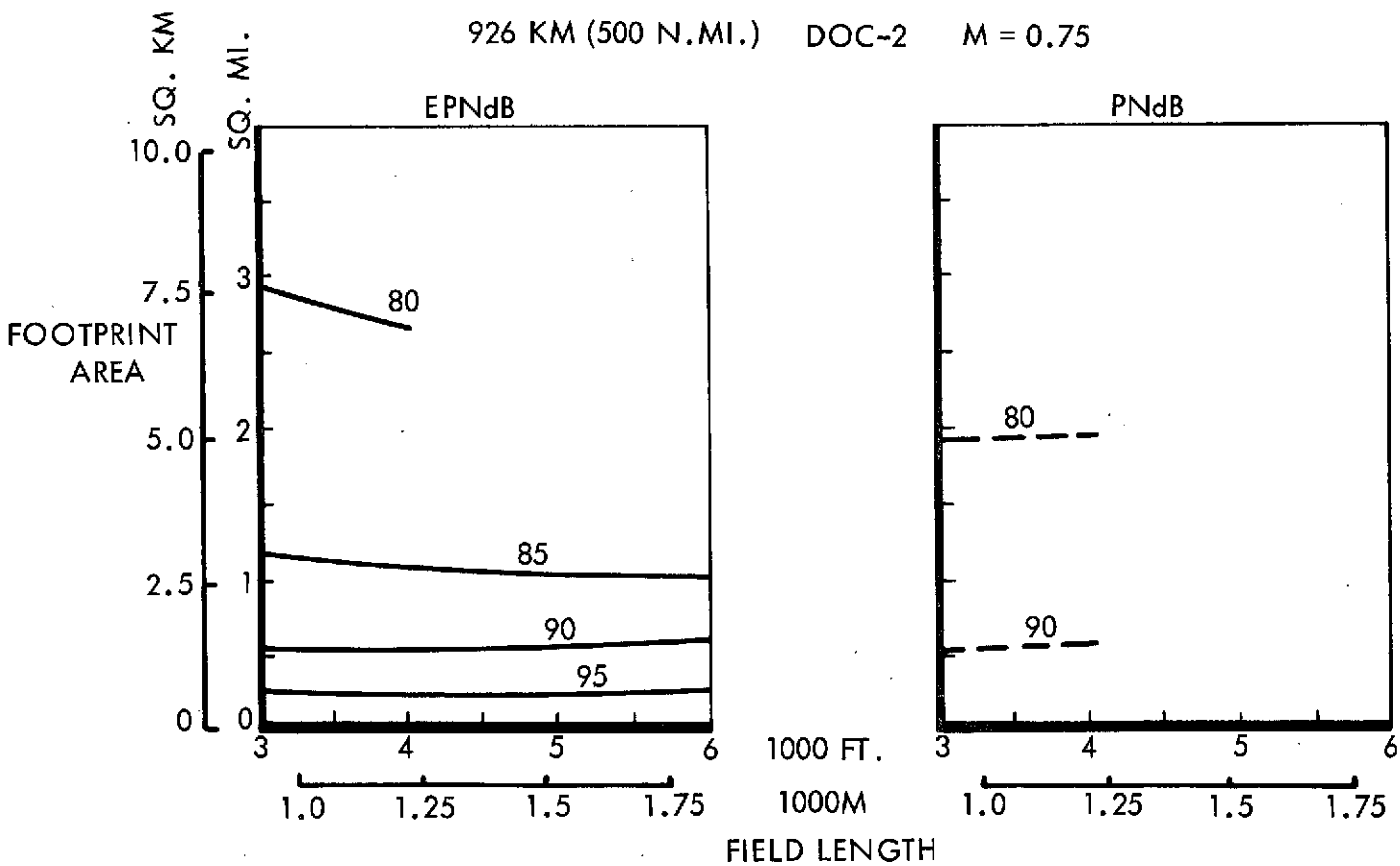


FIGURE 258 TAKEOFF FOOTPRINT AREA VS FIELD LENGTH (2-ENGINE MF)

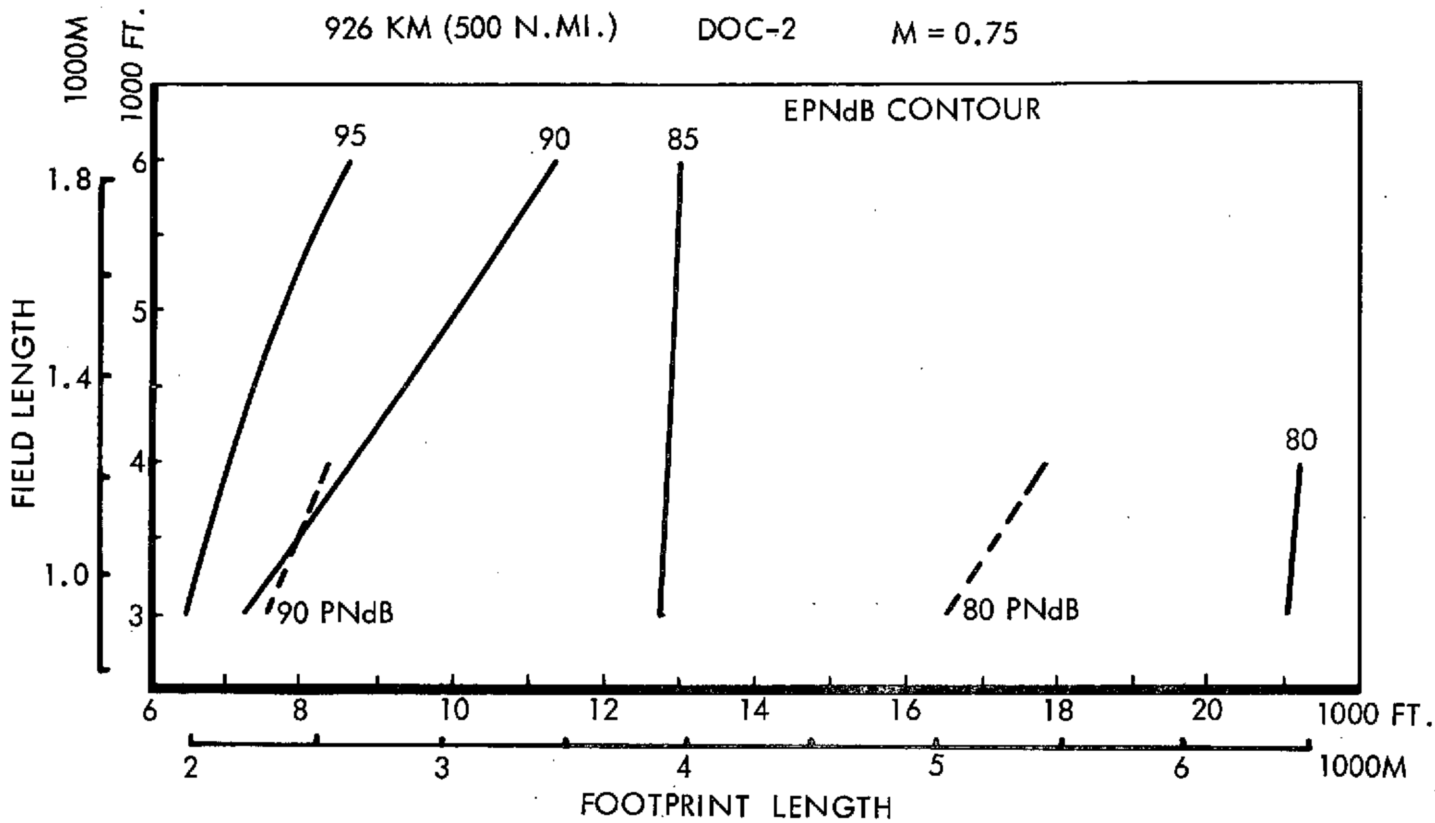


FIGURE 259 TAKEOFF FOOTPRINT LENGTH VS FIELD LENGTH (2-ENGINE MF)

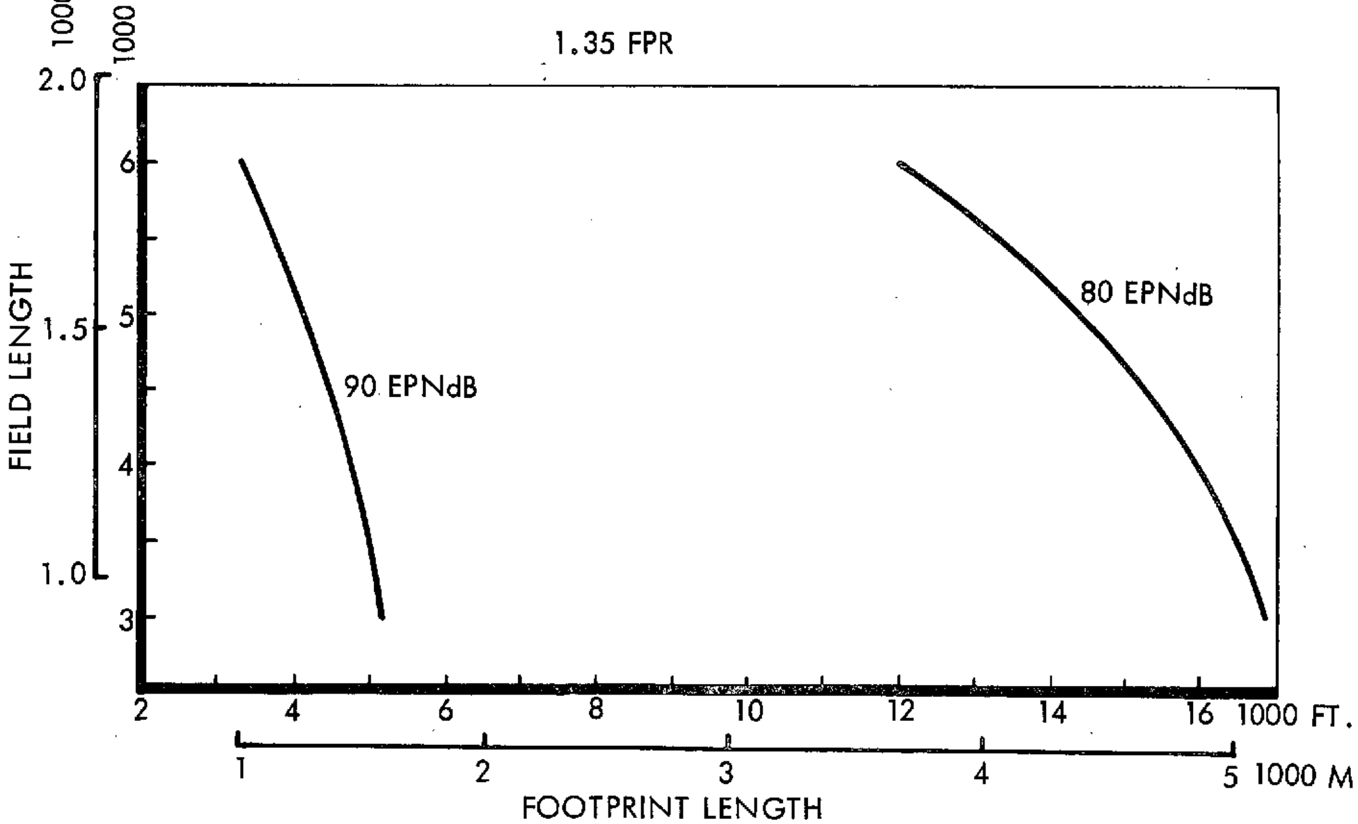


FIGURE 260 APPROACH FOOTPRINT LENGTH VS FIELD LENGTH (2-ENGINE MF)

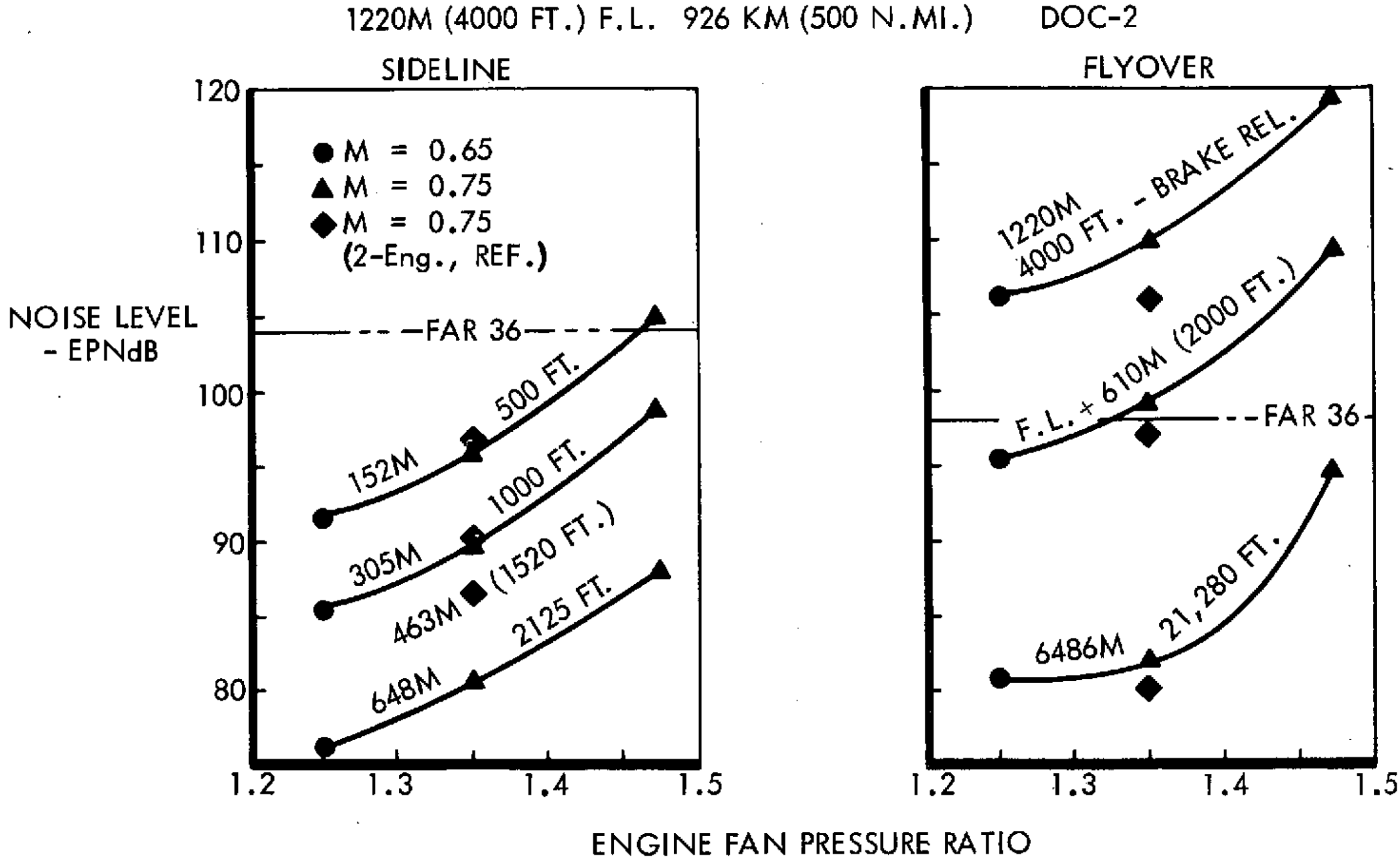


FIGURE 261 TAKEOFF NOISE LEVEL VS ENGINE FAN PRESSURE RATIO (4-ENGINE MF)

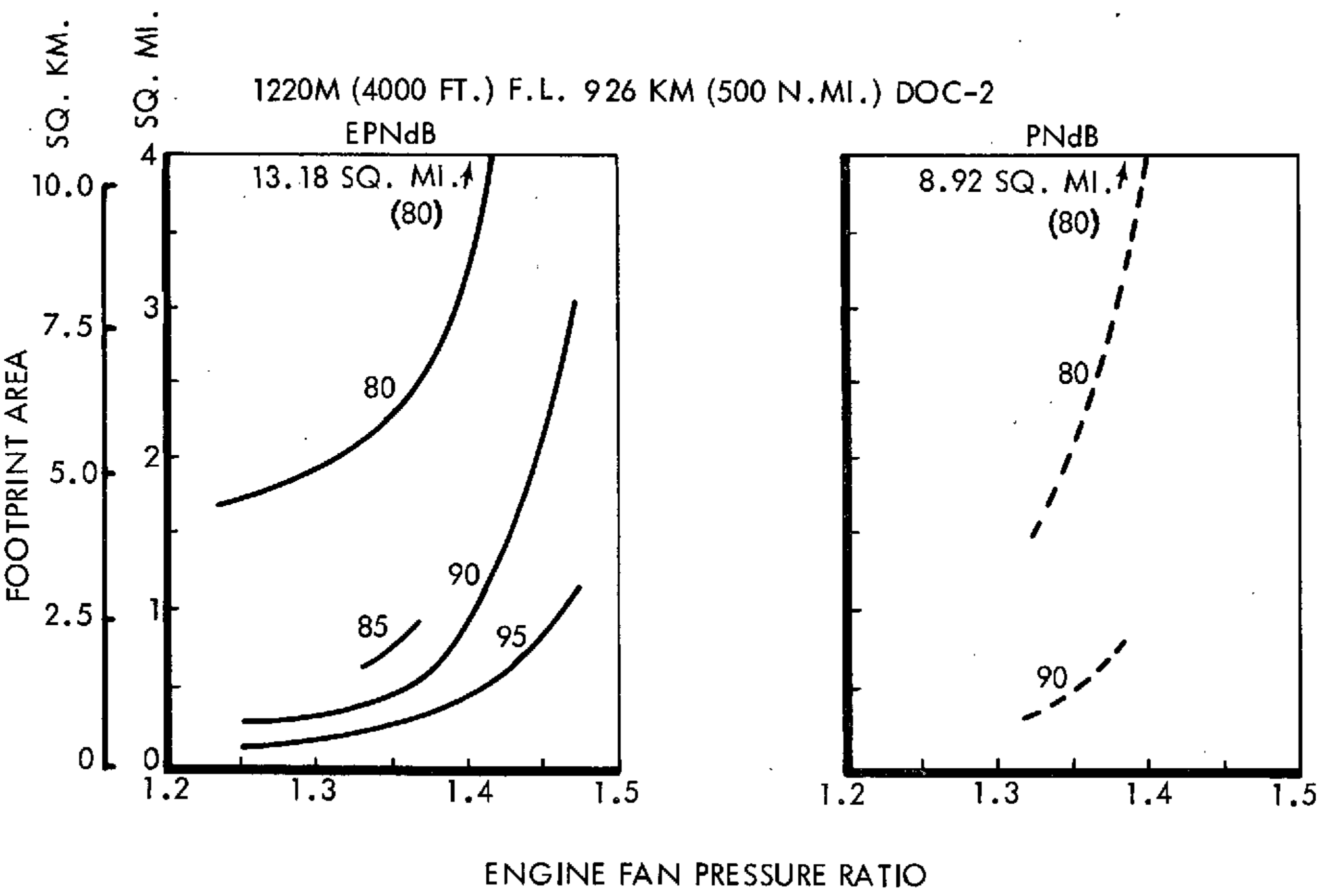


FIGURE 262 TAKEOFF FOOTPRINT AREA VS FAN PRESSURE RATIO (4-ENGINE MF)

with 1.35 FPR are also shown for reference. Footprint areas and lengths for these aircraft are plotted in Figures 262 and 263 . The direct operating cost at twice 1972 fuel prices (DOC-2) is shown as a function of sideline noise level in Figure 264 . It may be noted that the costs for achieving the noise level of the 1.35 FPR engine are very small; penalties for further reduction to noise levels of the 1.25 FPR engine are sharply increased. Similar relationships are shown for flyover noise level in Figure 265 and for takeoff footprint area in Figure 266 . Further discussion and comparison of these data are included in Section 8.

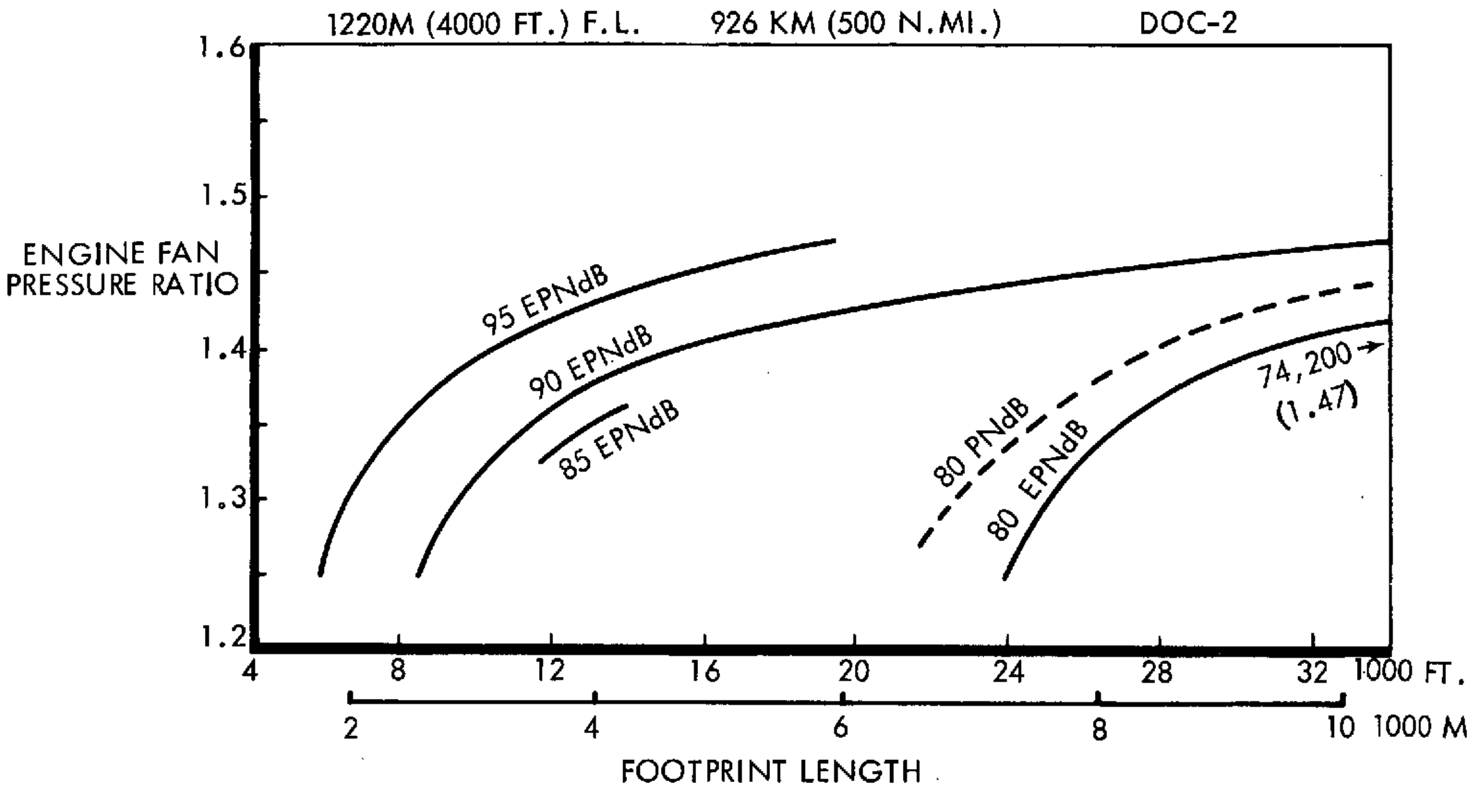


FIGURE 263 TAKEOFF FOOTPRINT LENGTH VS FAN PRESSURE RATIO (4-ENGINE MF)

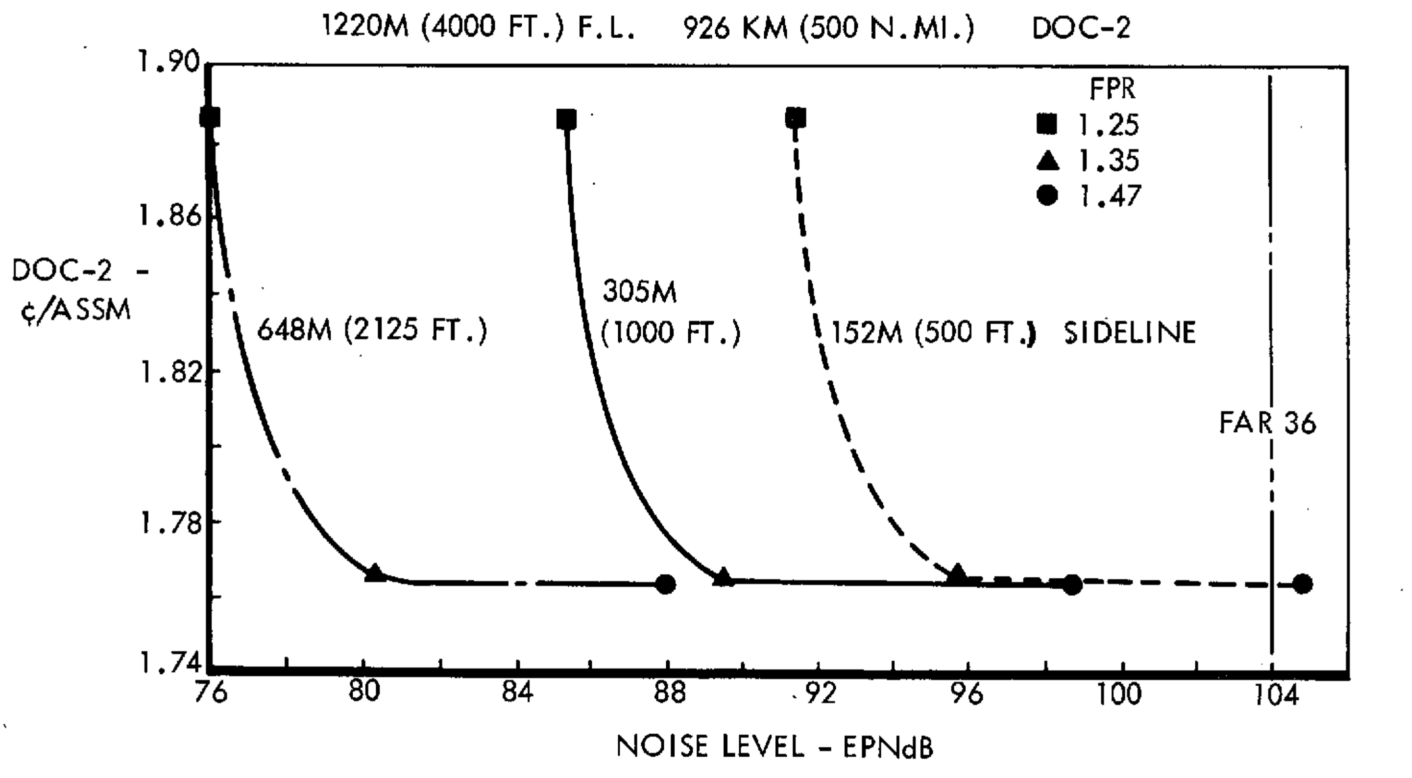


FIGURE 264 DOC VS SIDELINE NOISE LEVEL (4-ENGINE MF)

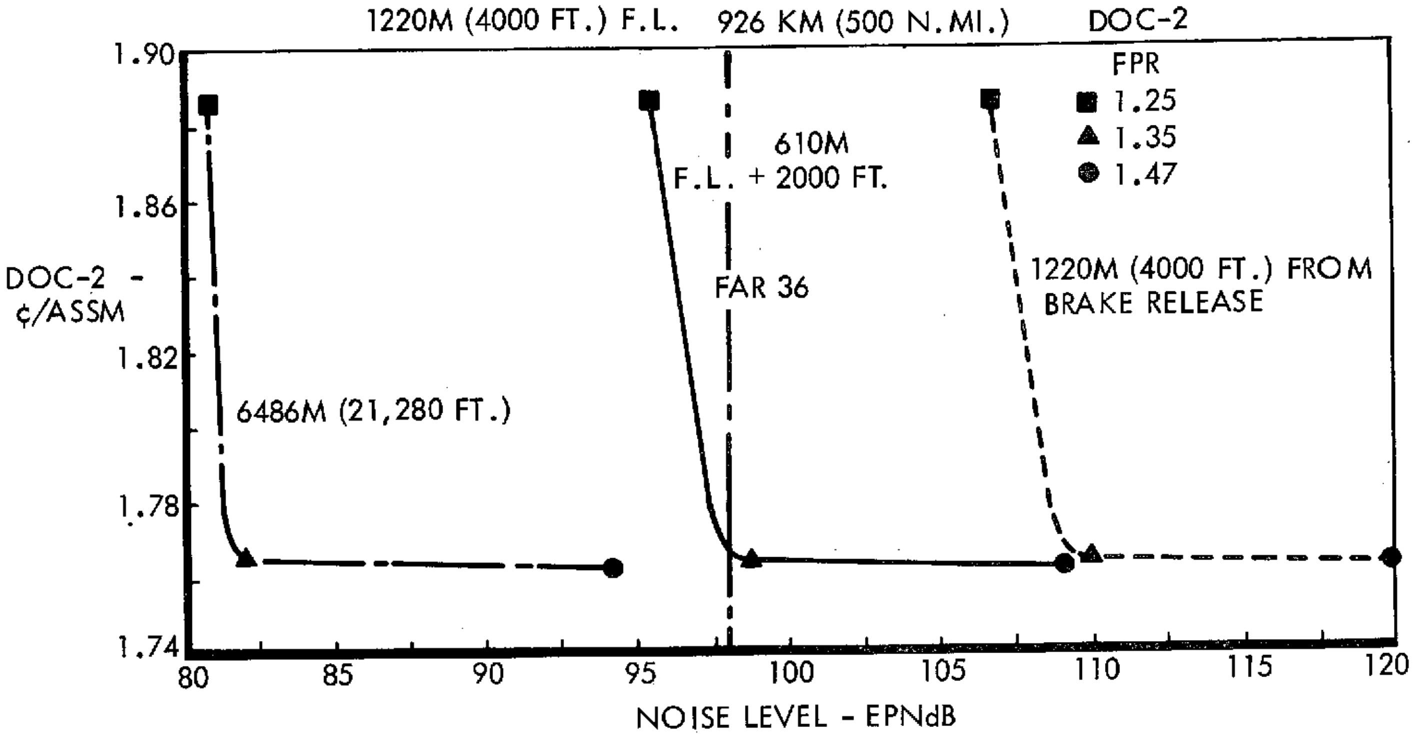


FIGURE 265 DOC VS FLYOVER NOISE LEVEL (4-ENGINE MF)

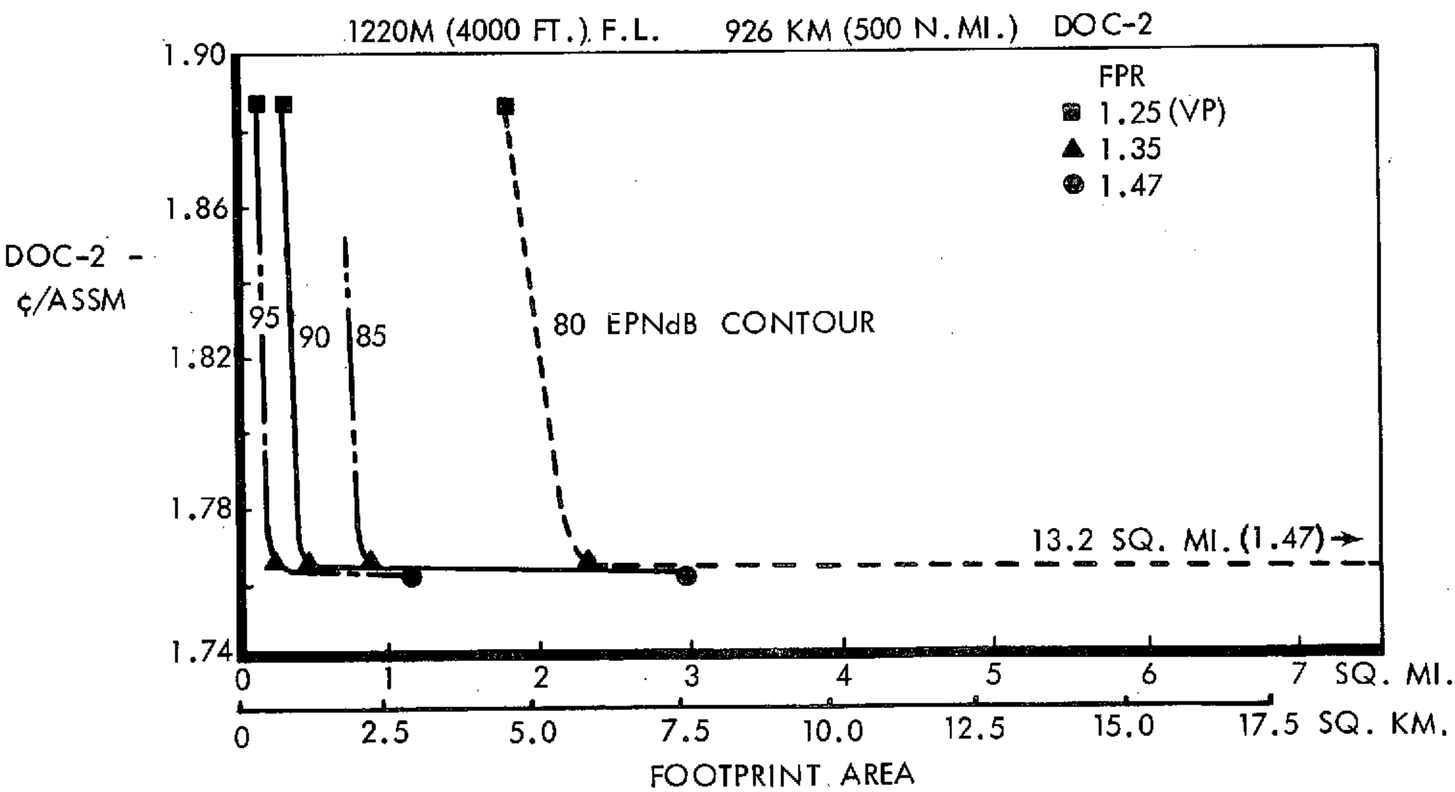


FIGURE 266 DOC VS FOOTPRINT AREA (4-ENGINE MF)

7.0 OTHER LIFT CONCEPTS

7.1 EXTERNALLY BLOWN FLAP (EBF) CONCEPT

Externally blown flap (EBF) concepts for 610m. (2000 ft.) and 914m. (3000 ft.) field lengths were included in the STOL System Study and have been reported in Reference 2 (NASA-CR114612). Both vehicles used a low (1.25) fan pressure ratio (FPR) engine, in order to comply with the selected noise criterion of 95 PNdB at 152m. (500 ft.) sideline distance. This is a lower FPR than that preferred for mechanical flap (MF) and hybrid over-the-wing/internally blown flap (OTW/IBF) concepts (to compensate for the flap generated noise component) and results in correspondingly higher direct operating costs (DOC). In the absence of any noise constraints, the optimum fan pressure ratio for least DOC at 1972 fuel prices would be expected to approach 1.5 as indicated by the mechanical flap studies of Reference 2. Because of the relatively low dynamic pressure (q) in the fan efflux, low FPR engines are sensitive to q -dependent thrust losses such as arise from scrubbing of the airplane surfaces and the lower the FPR the greater the percentage thrust loss. Effects such as these require the EBF vehicle to have generally higher installed thrust-weight ratios and lower wing loadings than the over-the-wing or upper surface blowing vehicles for a similar field length. Consequently, the DOC is slightly higher than that of the competing concepts as indicated in the comparison of the point designs from Reference 2 which is presented in Table XXXV and further illustrated in the noise comparisons in Figures 267 and 268. It will be noted that the point designs do not all match the target sideline noise level exactly because of the use of discrete FPR engine data. Figures 267 and 269 together show that if the EBF FPR were to be adjusted to give exactly the same sideline noise level as the OTW and OTW-IBF, the DOC would be reduced by some 2% (at FPR = 1.29) but the ranking of the concepts would not be affected. For these reasons, only the corroborative data presented in Table XXXVI has been developed in subsequent design studies.

Figure 270 illustrates the general arrangement of the 148 passenger EBF vehicle for 914m. (3000 ft.) field length which cruises at Mach 0.8 at 9140m. (30,000 ft.) and is listed in Table XXXV. This configuration is directly comparable with the baseline AW, OTW-IBF and MF vehicles described elsewhere in Sections 4.6, 5.6 and 6.6 of this report in

TABLE XXXV: COMPARISON OF LIFT CONCEPTS

148 PAX @ 0.8 M @ 9140 m. (30,000 FT.)

FIELD LENGTH	610 m. (2000 FT.)			914 m. (3000 FT.)			
CONCEPT	EBF	OTW	AW	EBF	OTW	OTW-IBF	MF
FPR	1.25	1.325	3.0	1.25	1.325	1.325	1.35
NO. ENGINES	4	4	4	4	4	2	2
ASPECT RATIO	6.5	6.5	6.5	6.5	6.5	7.0	7.0
SWEEP - DEG.	30	30	30	30	30	30	30
RGW - Kg (LB)	83,002 (182,989)	76,113 (167,800)	88,773 (195,710)	66,428 (146,449)	61,857 (136,372)	66,837 (147,350)	76,607 (168,890)
OWE - Kg (LB)	58,036 (127,947)	51,891 (114,400)	61,970 (136,620)	44,239 (97,531)	39,999 (88,183)	44,565 (98,250)	52,590 (115,940)
T/W	0.590	0.543	0.383	0.512	0.456	0.453	0.470
W/S - Kg/m^2 (psf)	357 (73.2)	357 (73.2)	395 (81.0)	456 (93.3)	481 (98.6)	455 (93.2)	298 (61.0)
DOC (1) - ¢/ASSM	2.24	2.14	2.18	1.94	1.87	1.80	1.93
PNdB @ 152m. (500 FT.) SIDELINE	93.9	-	93.5	91.8	94.0	95.4	-
80 PNdB FOOTPRINT (Km^2) (SQ. MILES)	11.7 (4.5)	- (-)	7.3 (2.8)	16.8 (6.5)	9.8 (3.8)	7.3 (2.8)	- (-)

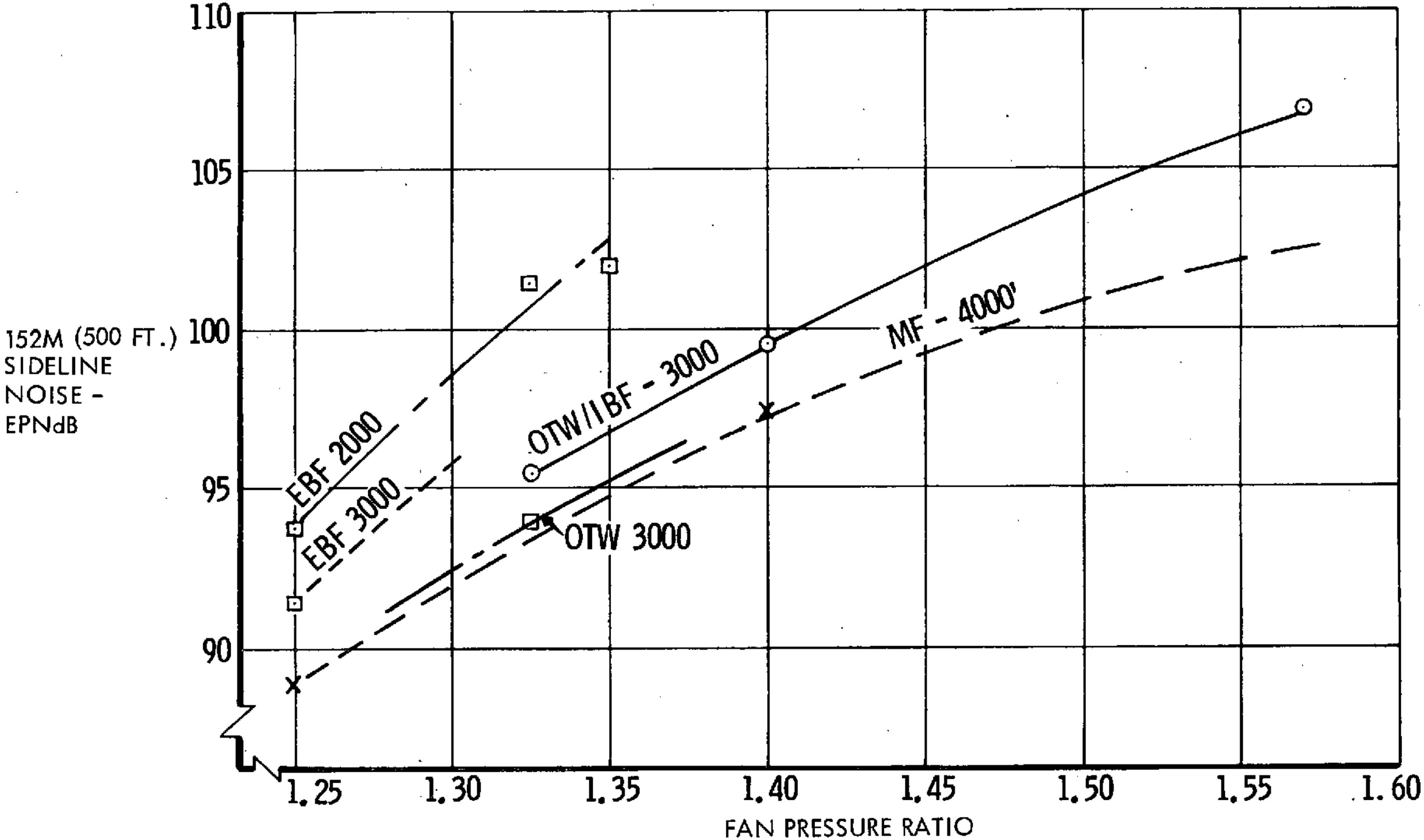


FIGURE 267 SIDELINE NOISE RELATED TO FAN PRESSURE RATIO

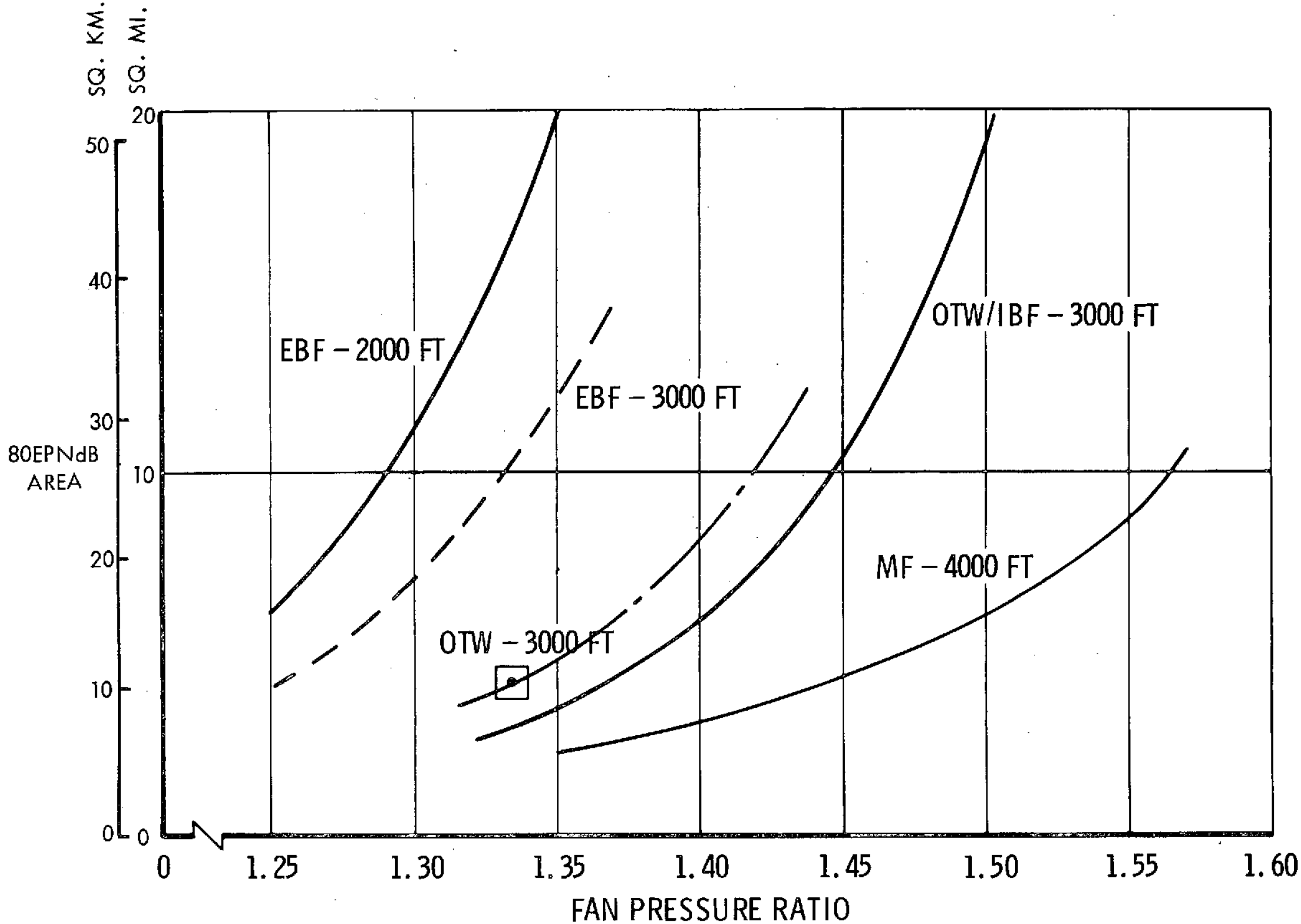


FIGURE 268 EFFECT OF FPR ON 80 EPNdB TAKEOFF FOOTPRINT

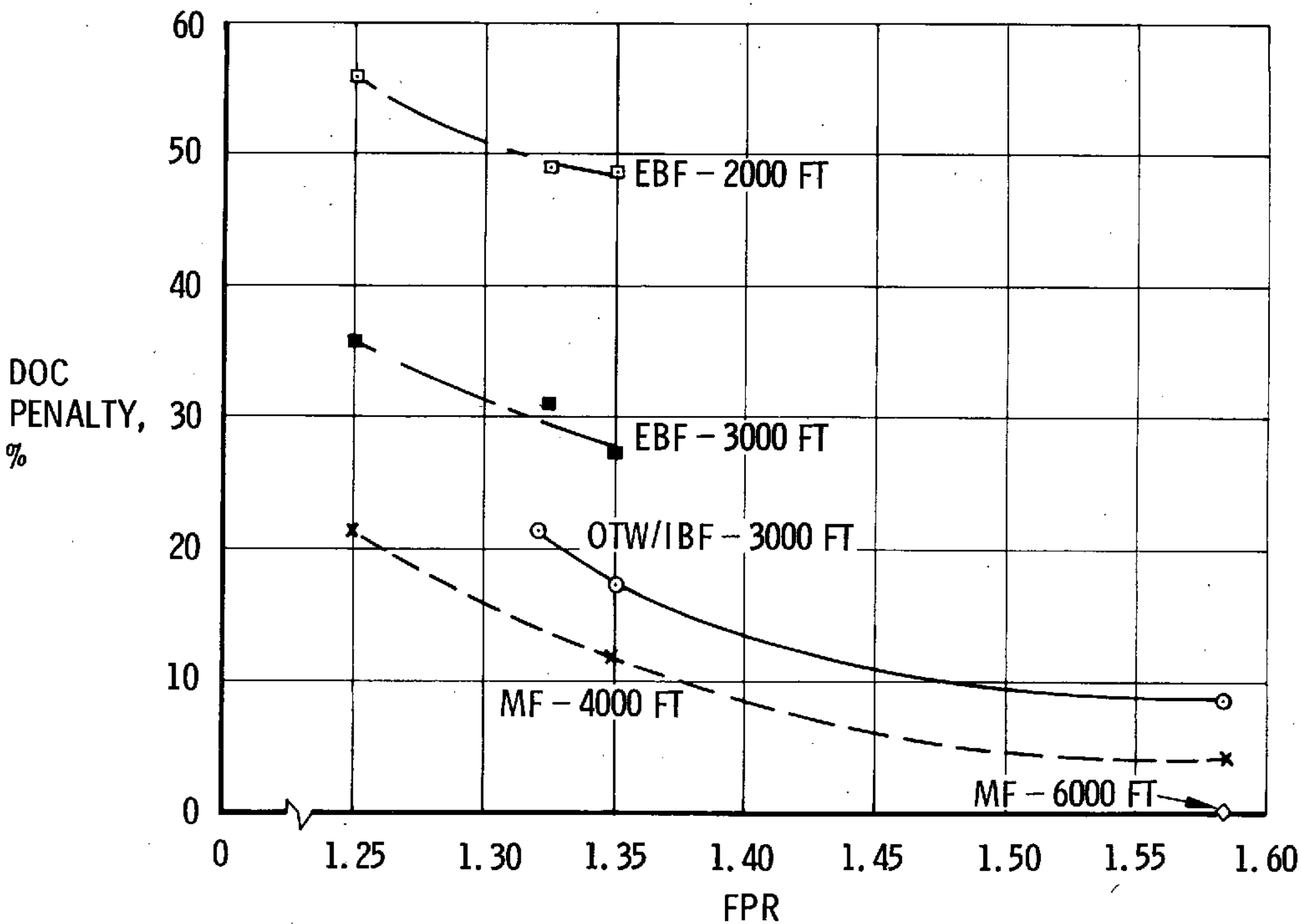


FIGURE 269 EFFECT OF FAN PRESSURE RATIO ON DOC

FIELD LENGTH - FT. (M.)	2000 (610)	3000 (910)
NO. OF ENGINES	4	4
FPR	1.25	1.25
MACH NUMBER	0.65	0.65
CRUISE ALTITUDE - FT. (M)	30,000 (9140)	30,000 (9140)
AR	10	10
SWEEP - DEG.	10	10
$W/S_{T/O}$ LB/SQ. FT. (KG/SQ.M)	66.6 (325)	81.0 (395)
$T/W_{T/O}$	0.423	0.325
RGW LB (KG)	147,760 (67,020)	124,270 (56,370)
OWE LB (KG)	99,780 (45,260)	81,250 (36,860)
MISSION FUEL - LB (KG)	11,030 (5000)	9760 (4430)
DOC-1 — ¢/ASSM	1.968	1.844
DOC-2 — ¢/ASSM	2.196	2.046

TABLE XXXVI: EBF - AIRPLANE CHARACTERISTICS OPTIMIZED FOR MINIMUM DOC-2

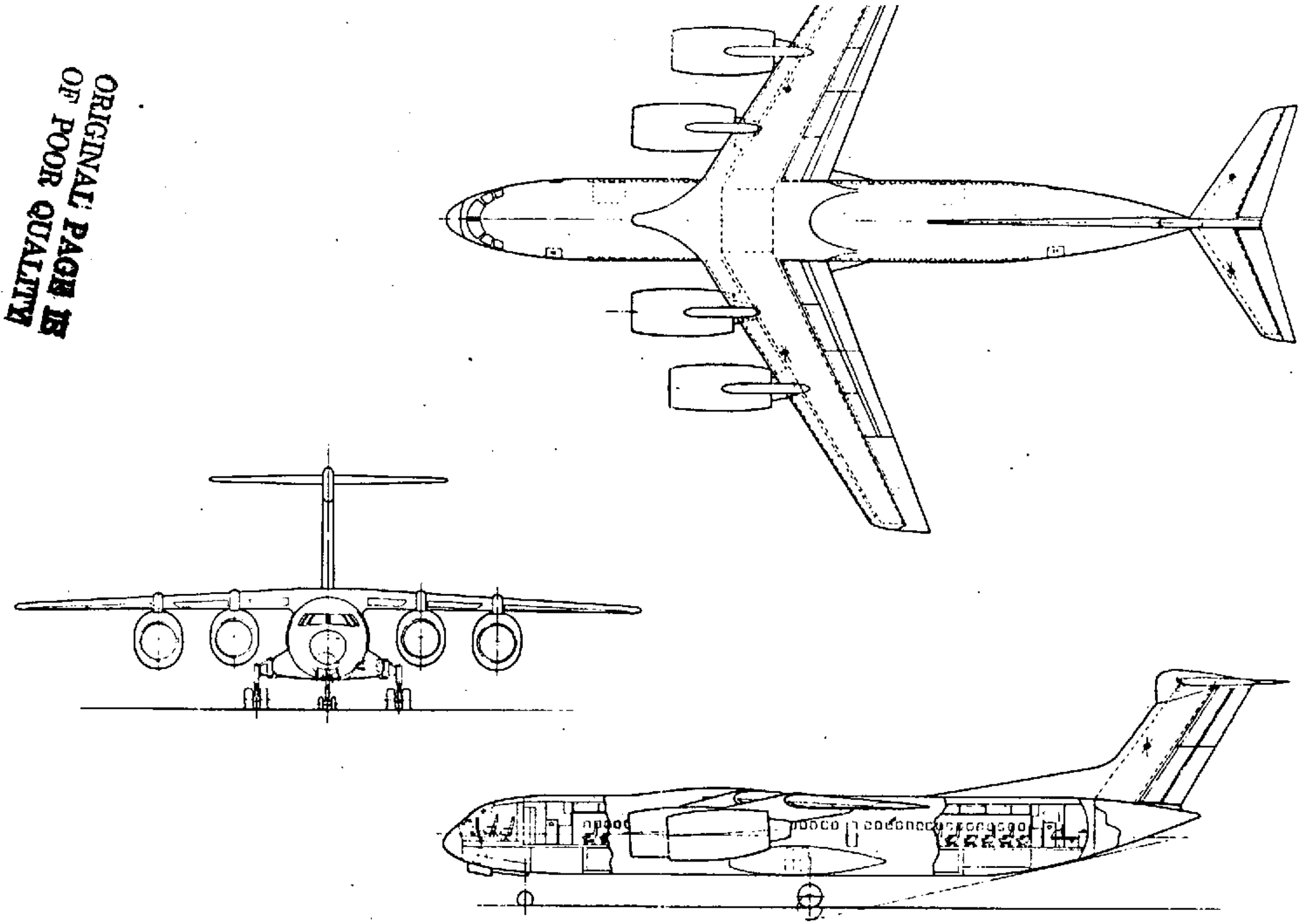


FIGURE 270 EBF AIRPLANE: GENERAL ARRANGEMENT

terms of mission capabilities but does not necessarily reflect the optimum aspect ratio and sweep. A four engine arrangement as shown is mandatory for this concept in order to restrict the asymmetric lift loss and rolling moment consequent to an engine failure to manageable proportions. Hence, the potential DOC advantages of the two-engine arrangement which benefit the OTW-IBF and MF concepts cannot be realized by the EBF. Compliance with one engine-out takeoff climb gradient requirements in a two-engine configuration necessarily affords a distinctly superior climb gradient in the normal all-engine operating case to that attainable by a four engine configuration. This substantially reduces the noise level at a flyover measuring point, shortens the footprint and reduces its area as illustrated by the data presented in Figure 268 with respect to the two-engine OTW-IBF and MF concepts.

Comprehensive descriptive material for this concept including weight and balance data, performance and ride quality data is contained in Reference 2.

7.2 OVER THE WING CONCEPT (OTW)

The pure over-the-wing (OTW) lift concepts was also included in the earlier study reported in Reference 2 from which the comparative data in Table XXXV and Figures 267 through 269 have been extracted. Although this concept permits a higher fan pressure ratio than that of the EBF in complying with similar sideline noise criteria, it is similarly restricted to a four engine arrangement because of the engine-out rolling moment. Thus, although it has a DOC which is marginally superior to the augmentor wing, as Table XXXV shows, it is inferior to the two engine OTW-IBF from both the DOC and noise aspects (if footprint area is taken to be the discriminating factor between vehicles designed to similar sideline noise levels). For these reasons, the OTW concept per se has not been included in the concepts represented in subsequent studies. The consideration of the hybrid OTW-IBF concept in its most general form (with thrust split as a variable) as reported in Section 6.1 includes a close approximation to the pure OTW concept as one extreme (zero IBF flow). Hence, the derivation of a non-zero IBF flow for the optimum thrust split (minimum DOC 1) tends to confirm its exclusion. However, this is not absolutely conclusive with respect to either minimum mission fuel (or minimum DOC configurations at elevated fuel costs) since the four-engine vehicle has generally appeared advantageous in this regard for each of the concepts retained in fuel conservation studies. Moreover, the generalized OTW-IBF concept reduces to a plain flap at zero IBF flow which is clearly inferior to a combination of Coanda flap in the nacelle region and a slotted flap elsewhere as would be proposed for an optimized pure OTW. For these reasons, the four engine OTW must continue to be regarded as at least a competitive concept and its relative standing remains to be determined.

Figure 271 illustrates the general arrangement of the 148 passenger OTW vehicle for 910m. (3000 ft.) field length which is fully described in Reference 2. This is directly comparable with the baseline vehicles using OTW-IBF, AW and MF high lift concepts described in earlier sections of this report except that the aspect ratio and sweep have not been optimized.

7.3 BOUNDARY LAYER CONTROL CONCEPT (BLC)

Orthodox BLC systems have not been considered beyond the studies reported in Reference 2. BLC concepts were confined to four engine arrangements with discrete BLC ducts and fan pressure ratios between 1.2 and 1.5. Because of these low pressure ratios, the proportion of the fan flow which could be diverted to the BLC system without excessive duct loss was relatively small and corresponded to an all-engines operating C_μ of 0.15 which preserves attached flow following engine failure but does not reflect a very significant jet flap lift component. In order to fully realize the potential BLC lift component on landing with high engine power settings, it was necessary to restrict the forward thrust component since this system does not yield the high drag levels desired per se. Hence, the major part of the fan air thrust was vectored using underwing Pegasus-type nozzles for both cruise and STOL modes. Consequently, the optimum fan pressure ratio proved to be higher than was acceptable from the noise standpoint and was limited to 1.3, at which value the losses associated with the vectoring nozzles adversely affected the cruise sfc. As indicated in Table XXXVII, which presents comparisons

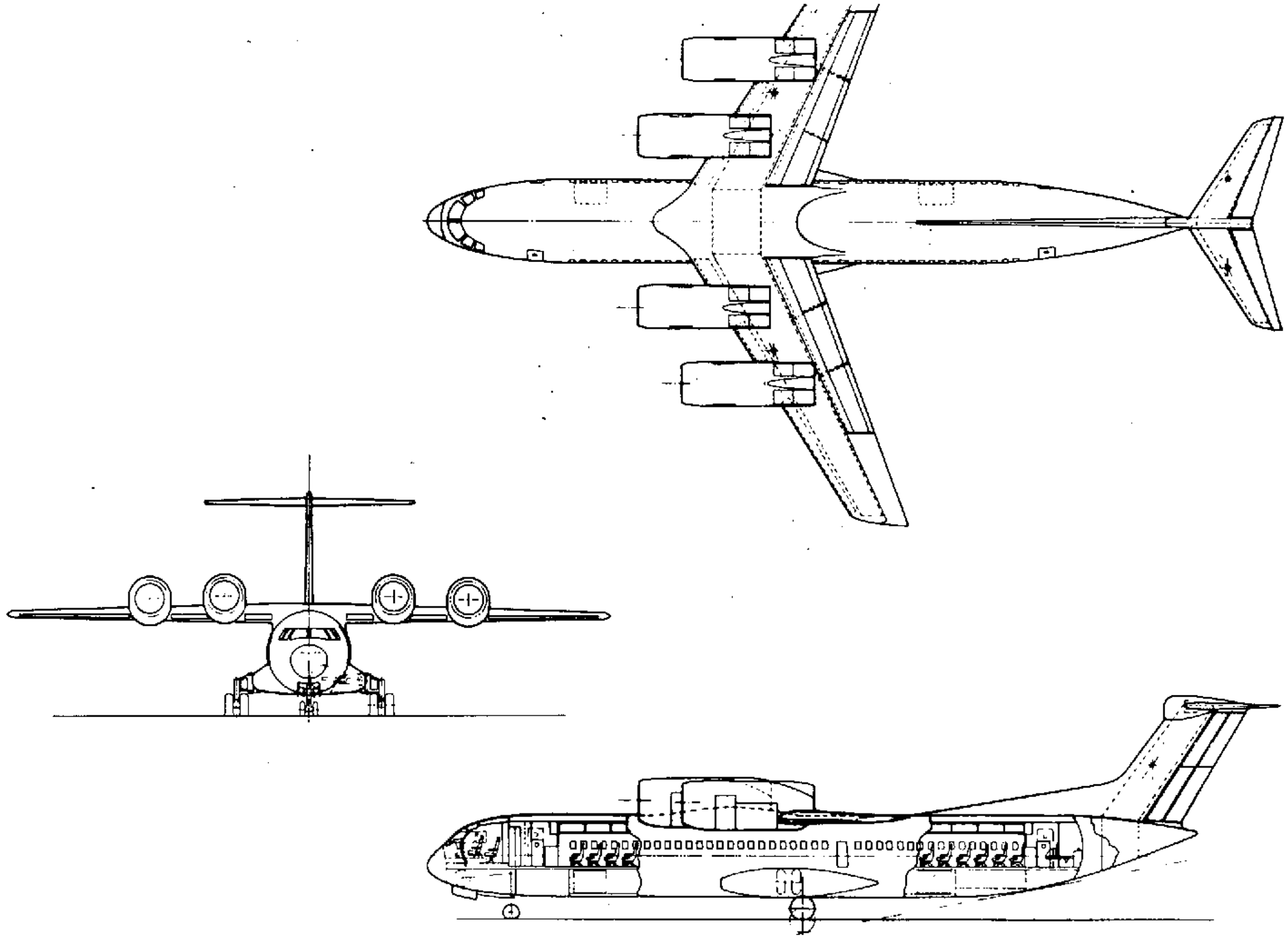


FIGURE 271 OTW AIRPLANE: GENERAL ARRANGEMENT

100 PAX @ 0.8 M @ 9140 m. (30,000 FT.)

FIELD LENGTH	610M (2000 FT.)			914M (3000 FT.)		
CONCEPT	EBF	AW	BLC/VT	IBF/WT	AW	BLC/VT
FPR	1.25	3.0	1.30	1.30	3.0	1.30
NO. ENGINES	4	4	4	4	4	4
ASPECT RATIO	6.5	6.5	6.5	6.5	6.5	6.5
SWEEP - DEG.	30	30	30	30	30	30
RGW - Kg (LB)	48,959 (107,937)	50,459 (111,242)	71,441 (157,500)	50,175 (110,618)	42,494 (93,683)	48,096 (106,033)
OWE - Kg (LB)	33,999 (74,955)	34,206 (75,412)	52,897 (116,618)	34,855 (76,842)	27,571 (60,784)	33,100 (72,972)
T/W	0.567	0.385	0.518	0.597	0.332	0.456
W/S - Kg/m^2 (psf)	364 (74.6)	399 (81.8)	293 (60.0)	459 (94.1)	484 (99.2)	439 (90.0
DOC-1 - ¢/ASSM	2.45	2.34	2.89	2.42	2.10	2.30

TABLE XXXVII: COMPARISON OF LIFT CONCEPTS of representative conceptual vehicles from previous Reference 2, for both 610m. (2000 ft.) and 914m. (3000 ft.) field length, the BLC/VT concept was shown to be radically inferior to its competitors and was excluded from further development studies. Figure 272 presents the general arrangement of this concept.

7.4 INTERNALLY BLOWN FLAP CONCEPT (IBF)

The use of the flap itself as an expanding duct for the distribution of blowing air as in the Jacobs-Hurkamp internally blown flap (IBF) concept is more appropriate to low fan pressure ratio systems than the BLC concept previously described. Consequently, IBF high-lift systems were included in the conceptual studies described in Reference 2. A four engine plenum duct arrangement was assumed in order to maximize the air flow to the IBF system with the tacit assumption that the stable engine operating problems raised by their paralled operation in this manner would be amenable to solution. Nevertheless, the intrinsically high duct losses associated with the low FPR restricted the proportion of the fan air diverted to the IBF system to 18.75%. For similar reasons to those already noted with respect to BLC systems, vectoring of the major part of the fan airflow via underwing Pegasus nozzles proved necessary and noise constraints similarly restricted the fan pressure ratio to 1.3. A representative IBF/VT vehicle utilizing these principles is included in the comparisons presented in Table XXXVII. From this it will be noted that, although the internally blown flap permits a substantially high than the BLC system and a correspondingly better STOL performance which is reflected in a radically greater attainable wing loading [461 Kg/m^2 (94 lb./sq.ft.) at 610m. (2000 ft.) field length], the DOC remains inferior to both the AW and EBF vehicles. It was therefore apparent that the more efficient vectoring of the fan airflow and the noise shielding which the OTW concept allows could be utilized effectively by the elimination of the vectoring nozzles and the diversion of the major part of the fan airflow to an OTW component in the hybrid OTW-IBF concept already described. Hence, further development of the original IBF concept as illustrated in the general arrangement of Figure 273 was abandoned after the completion of the conceptual studies. Reference 2 contains a more detailed discussion of this concept and its capabilities.

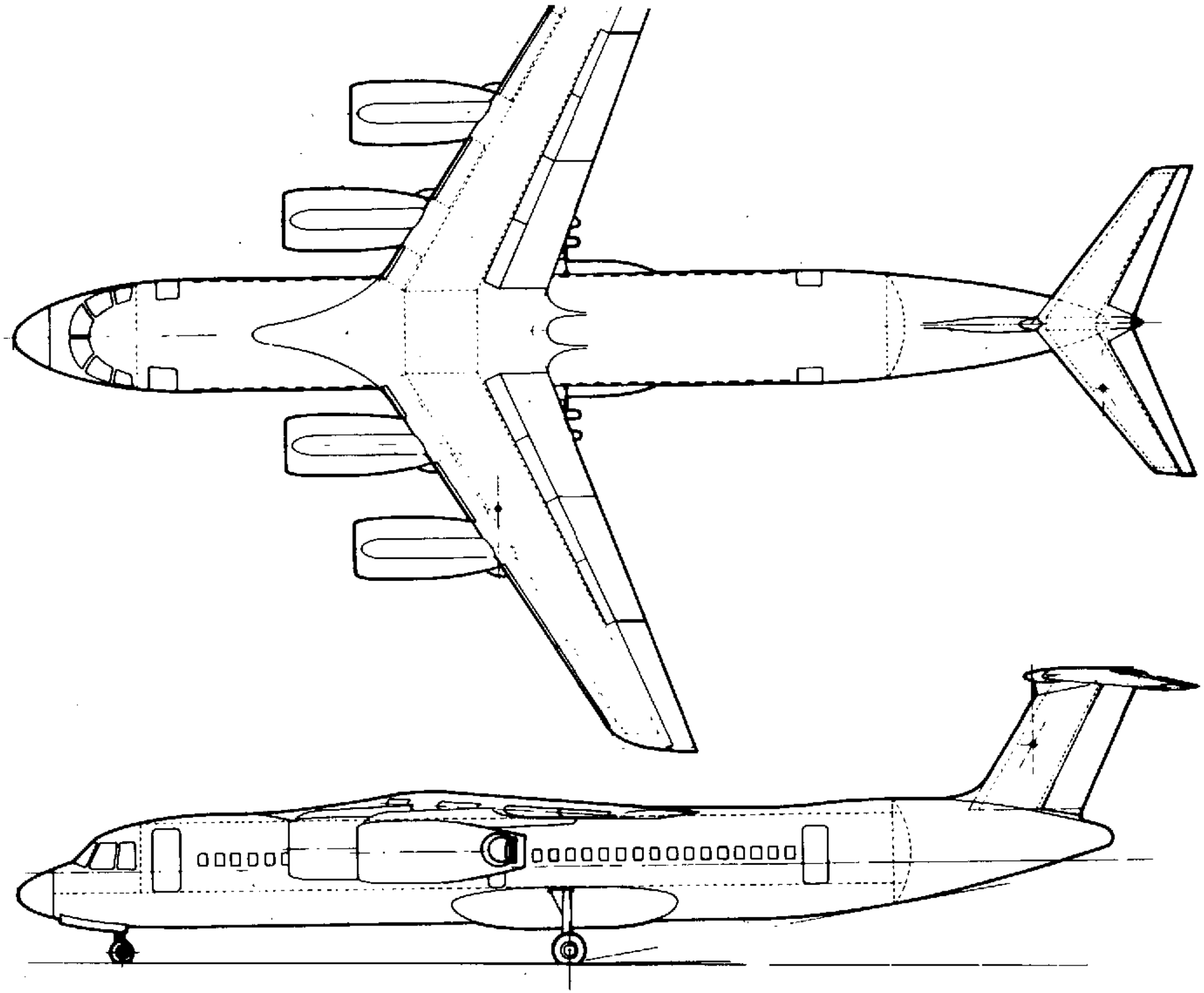


FIGURE 272 BLC AIRPLANE: GENERAL ARRANGEMENT

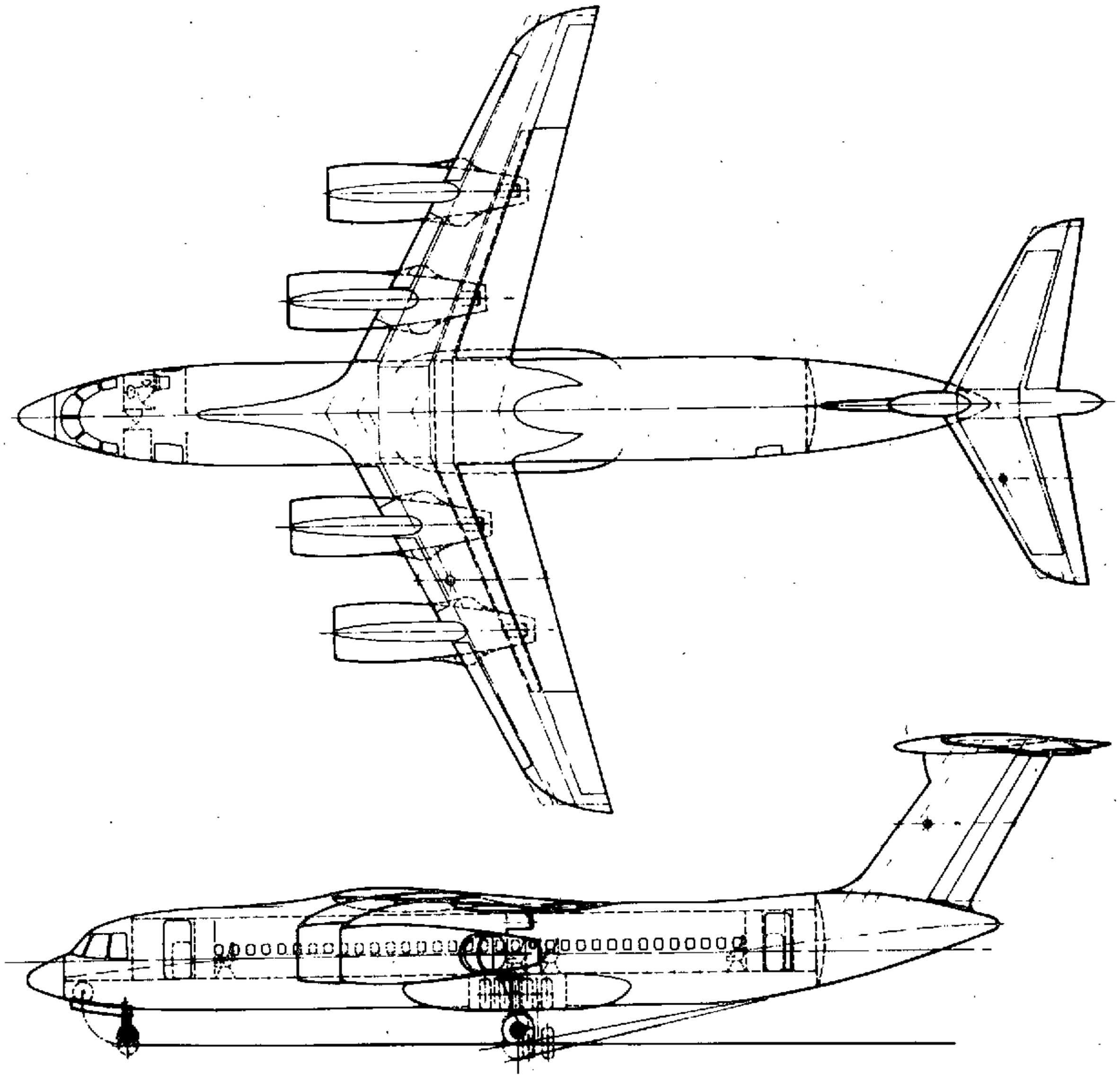


FIGURE 273 IBF AIRPLANE: GENERAL ARRANGEMENT

7.5 DEFLECTED SLIPSTREAM VEHICLES

7.5.1 Concept

Historically, propeller driven airplanes have yielded substantially lower fuel consumptions than the turbofan aircraft which have largely supplemented them. With the technology available throughout the last decade as a basis, cruise specific fuel consumptions as low as 0.17 Kg/CV/hr (0.39 lb/eshp/hr) have been projected. At M = 0.5 and with a propeller efficiency of 0.8, the equivalent in terms of turbofan sfc is 44.6Kg/KN/hr (0.44 lb/lb/hr) which is a lower sfc than that of any of the low FPR turbofans under consideration. For this reason alone the turboprop qualifies for inclusion in a comprehensive evaluation of fuel-conservative vehicles (and may be regarded as representing the limiting case of low FPR in this context). Moreover, the use of slipstream-generated lift qualifies as a powered lift concept under FAR XX performance ground rules although credit for this lift margin may not be taken into account in commercial propeller driven airplanes certified under FAR 25. Accordingly, the concepts included in the study have been extended to cover analyses of short-haul aircraft designed for fuel conservation with simulated turboprop propulsion. Their performance has been based solely on deflected slipstream propulsive lift effects without other provisions for augmenting lift because this can be shown to be most economical for field lengths of 910m (3000 ft.) and above. As for the other concepts, the design mission requirements were a capacity payload of 148 passengers, associated with range of 926km (500 n.m.), and field lengths of 910m to 1830m (3000 ft. to 6000 ft.).

A conventional low wing configuration with an aspect ratio of 14.0 has been assumed for all the vehicles examined since lower aspect ratios have been shown to be inferior in both DOC-2 and mission fuel for other lift concepts at cruise speeds under Mach 0.7. At the higher cruise C_L associated with typical turboprop cruise speeds between Mach 0.5 and 0.6, the advantage of this high aspect ratio becomes even more pronounced. Similarly, only four engine configurations have been examined because of the indications of superior fuel consumption and DOC for this arrangement afforded by the other lift concepts at cruise speeds below Mach 0.8. (Moreover, the single engine roll control problems of two engine powered lift configurations in general are evaded.

The T56-A-15 turboprop engine, manufactured by the Detroit Diesel Allison Division of GMC, was selected as the baseline turboprop for this study. While this engine is not representative of the latest technology, the immediate availability of engine data within Lockheed was the dominant factor in its selection. Similarly, the 4.1m (13.5 foot) diameter Hamilton Standard 54H60-91 propeller was selected as the basis for propeller performance. Both of these units are used on the Lockheed C-130 series of aircraft and installed performance data are available over the flight spectrum required for this study. Although the performance of this propeller per se is fully representative of modern technology, the noise level is 106 PNdB at the 152m (500 ft.) sideline at a 44.5kN (10,000 lb.) thrust level whereas that of the fan-powered aircraft is approximately 10 dB better. A larger diameter propeller turning at a lower tip speed has been designed by Hamilton Standard to give 95 EPNdB at the 152m (500 ft.) sideline and the corresponding supplementary data to show the implications of quietening the propeller have been included in subsequent sections of this report.

7.5.2 Deflected Slipstream Aerodynamic Data

Aerodynamic performance for the deflected slipstream concept has been based on detailed C-130 cruise and terminal operating data from which slipstream effects have been derived. In determining thrust and wing area requirements for takeoff and landing the power-on stall speeds (including one-engine inoperative) were used as covered in FAR Part XX rather than the power-off stall speeds represented in Part 25. (Thus the design criteria are compatible with other powered-lift cases.) The alternate application of FAR Part 25 requirements for power-off stall speed would have a significant effect in reducing the attainable wing loading, with a consequent increase in the required thrust. Hence both the fuel consumption and direct operating cost would be appreciably greater. It should be noted that the improvements obtainable by applying Part XX to a mechanical flap airplane are obtained without penalty only in the case of propeller or "deflected slipstream" aircraft; with fan or jet power, no improvement in stall speed can be gained without a penalty for the propulsive-lift provisions.

7.5.3 Deflected Slipstream Propulsion Data

The basic T56-A-15 engine and propeller data generated for use in preparing C-130 flight handbooks was utilized. These data are for actual engine performance and include installation effects for inlet, exhaust, power extraction, compressor air bleed, and propeller performance at appropriate pitch for the flight conditions. The inlet, exhaust, and propeller characteristics as included in these data were acceptable for this study while the bleed air and power extraction levels for the study airplane deviated significantly from those included in the data. As a consequence, modifications were required for these two installations influences.

When corrections were applied to the engine data for the increased bleed airflow required for the short haul airplane, the deterioration in engine performance appeared excessive. A brief comparison was made between compressor bleed and geared auxiliary compressors driven off the engine gearbox. The comparison was made for 7620m (25,000 ft.) altitude at 0.55 Mach normal power conditions. The results of this comparison were as follows:

	Airplane Compressed Air Source	
	Compressor Bleed	Geared Compressor
Fuel Flow	553Kg/hr (1220 lb/hr)	576Kg/hr (1270 lb/hr)
Shaft Power	2397CV (2364 HP)	2620CV (2584 HP)
TSFC	57.0Kg/KN/hr (0.5585 lb/lb/hr)	53.8Kg/KN/hr (0.5272 lb/lb/hr)

Power sections for these alternatives were then scaled to produce the same propeller shaft horsepower value as that of an engine operating with neither compressor bleed nor geared compressors and the weight increments were evaluated as follows:

	Airplane Compressed Air Source			
	Compressor Bleed		Geared Compressor	
	Kg	lb	Kg	lb
Wt. Power Section	7.85	(173)	20.9	(46)
Geared Compressor Wt.	0	0	45.4	(100)
Weight Total:	78.5	(173)	66.3	(146)

The weight shown for the geared compressor is based on a scale-up of the units used on the Lockheed Electra and includes a weight increment for a modification to the engine gearbox.

to provide the additional drive pad. From this comparison, it was concluded that a slight weight saving could be realized from use of the geared compressor with a 3.5 percent improvement in TSFC. Geared compressors were therefore adopted and the existing data were modified to eliminate the performance degradations for compressor bleed. The power extraction for the geared compressor as well as the increment for other power extractions between the short haul requirements and the extraction included in the data was deducted from the available propeller shaft horsepower.

The shaft horsepower data were converted to propeller thrust using curves of propeller characteristics prepared for C-130 performance evaluations. These propeller data were limited to flight speeds of 0.55 and below. Data were desired for flight speeds up to 0.65 Mach so additional propeller data were computed to include this speed. The Hamilton Standard 54H60-91 propeller was optimized for C-130 cruise conditions of approximately 0.5 Mach and its characteristics were considered suitable for the short haul airplane. The additional propeller data were computed for the higher Mach assuming optimization for the higher cruise speeds.

The airplane performance computer programs used in the short haul study have been oriented to utilizing fan-jet type engines in which the engine performance is assessed as the net thrust of the engine nacelle. This net thrust includes all internal and external loss and drag terms. This differs from the bookkeeping system employed on the C-130 in which the engine performance is assessed as the propeller thrust plus the power generator ram drag and jet thrust with all nacelle drag and prop wash effects included in the airplane drag. It was therefore necessary to make a further modification to the existing data to include the drag associated with the propeller wash over the nacelle and wing. The forebody and afterbody drags were assumed to be negligible because of the relatively small areas involved. The prop wash drag terms were evaluated taking the entire prop stream q over the wing surface in the prop wash. The wing area subjected to the prop wash was taken as a spanwise sector of the wing equal to the propeller diameter. These drag terms, together with the power generator ram drag and jet thrust were applied to the propeller thrust term to determine an installed net thrust for the propulsion unit. Installed SFC values were defined against this thrust term yielding installed engine data that could be utilized in the airplane computer programs in the same format as the data for turbo-fan engines. Basic T56-A-15 power generator and the current HS 54H60-91 propeller weights were assumed. The data for this combination are shown in Table XXXVIII.

A quiet propeller, based on lower tip speed and disk loading, was selected for further study. The data base for this propeller was generated by Hamilton Standard for a previous Lockheed study reported in Lockheed ER 10889, "Propeller STOL Transport Proposal for American Airlines." This propeller was designed for 95 EPNdB at 152m (500 ft.) sideline and was achieved by increasing the propeller diameter to 4.9m (16 ft.) for the T56 engine. The propeller design took advantage of advanced technology spar and shell composite construction and resulted in only a small weight penalty, including the weight penalty associated with a T56 gearbox change to provide the lower shaft speeds required. Cost increases for this propeller, including the distributed development costs of the propeller and the gearbox changes were more than offset by an increase in thrust at takeoff and the cost/thrust ratio at cruise only increased slightly. Since it showed generally improved performance with little penalty compared to the HS 54H60-91 propeller, this propeller was used for all engine derivative and advanced engine technology studies. Data for the T56-A-15 with this quiet propeller are also included on Table XXXVIII.

For a turboprop engine which is representative of more advanced technology, a turboprop version of the DDA 501-M62 was selected. DDA responded to solicitations in this regard with a free turbine turboprop version of the 501M62 identified as their Model PD370-11. This unit was created for this study and utilized the 501-M62 power section with minimum modifications. This power section is presently under development for application in the Heavy Lift Helicopter program. DDA provided computer print out data for the essential flight conditions for this study in a format and including parameters similar to those available for the T56-A-15 within Lockheed. The installation effects for the PD370-11 were dealt with in a manner similar to those described for the T56-A-15 installation and gear driven compressors were again assumed for supply of the airplane compressed air needs. Power extraction requirements were scaled to the same percent of base shaft horsepower as was used for the T56-A-15 to avoid incompatible evaluations between the T56-A-15 and PD370-11 evaluations when scaled. The characteristics of the Hamilton Standard

	T56-A15/Current Propeller		T56-A15/Quiet Propeller		PD370-11/Quiet Propeller	
	Uninstalled	Installed	Uninstalled	Installed	Uninstalled	Installed
Overall Pressure Ratio	9.5		9.5		12.3	
Airflow (Power Section) - Lb./Sec.	32.35		32.35		44.4	
ESHP	4910		4910		7896	
Thrust (Total, Prop. + Power Section) Lbs.	9749	9019	11798	10915	20241	18880
Weight (Power Section) - Lbs.	1845		1920		2190	
(Propeller) - Lbs.	1149		1107		1330	
Diameter (Max., Power Section + Gearbox) - In.	39		39		56	
(Propeller) - Ft.	13.5		16.0		21.3	
Length (Power Section) - In.	146		146		132	
Stages - Compressor	14		14		13	
Turbine	4		4		2&2	
TIT 1F	1970		1970		--	
T/W - T/O	3.25*	2.15	3.89	2.58	5.76	3.44
Price/Lb. Thrust - T/O	23.40**	38.50	20.70	31.90	23.89	35.90
Speed Lapse (M - 0.2)		.877		0.788		0.788
At 30,000 Ft., M - 0.6						
Thrust		1967		2046		2458
Lapse		.2180		.1736		.1302
SFCP		.5974		.5744		.5275

* Uninstalled T/O Thrust/Engine + Prop. and Controls Weights

** Engine + Prop. and Controls Price T/O Thrust Including Estimated Prop. Development Cost.

TABLE XXXVIII: TURBOPROP ENGINE/PROPELLER CHARACTERISTICS

Quiet Propeller were again assumed except scaled up to match the basic shaft power output of the PD370-11. DDA provided scale factors for this engine for dimensions and weights. Propeller weight was taken from Hamilton Standard parametric data and is scaleable as a function of shaft power.

After evaluation of the installed performance of the PD370-11 engine was completed, comparisons between the T56-A-15 and the PD370-11 did not show the anticipated advantages for the latter engine. This was iterated with DDA and determined to be a consequence of utilizing the DDA 501-M62 with minimum modification which resulted in significant compromises in the turboprop performance. DDA subsequently confirmed that an improvement of 12 percent in SFC was appropriate for this engine. Data for this concept of the PD370-11 are shown on Table XXXVIII. This engine, including the SFC improvement, along with turbofan engines of the PD370 family which are also based on the DDA 501-M62 gas generator were compared with the PD287 advanced technology engines used elsewhere in this study. The PD370-11, even with the improved SFC, proved significantly inferior to the PD287 series engines. This was to be expected since the PD370 series represents essentially current gas generator technology whereas the PD287 engines represent 1980 technology. It was therefore concluded that a further advanced technology engine was required. To this end, the PD370-11 series of engines was used as a guide in adjusting the SFC and T/W levels of the T-56 engine to the PD287 technology level. It was found that the cruise T/W values of the T-56 and the PD370-11 were comparatively close to those of the PD287 engines while the SLS takeoff values of T/W were appreciably different. This indicated a significant difference in lapse rate of the engines and a weight change for a given rated thrust which implies that a significant part of these differences result from the higher TIT and thrust of the advanced technology engines at the SLS takeoff condition.

Accordingly, factors were determined for application to the T56/Quiet Prop data to provide relative values for weight, SFC, lapse rate and cost of the advanced technology engines. These factors are shown on Table XXXIX. It will be noted that the individual factors when combined define the advanced technology engine with the exception of cost. The cost factor was based on a price increase that might be expected for a scaled T56 and

	RELATIVE PERFORMANCE FACTOR			DIMENSIONS		COST		REMARKS
	Rel. Wt.	Rel. SFC	Rel. Lapse Rate	Rel. Eng. Dia.	Length Nac. / Dia. Nac.	$ @	Rel. Thrust	
Baseline Eng.	1.0	1.0	1.0	1.0	4.58	244 K	1.0	T56-A-15 w/Quiet Prop.
SFC Development Engine	1.0	.7845	1.0	1.0	4.58	244 K	1.0	Baseline w/Adv. Tech. SFC
Weight/Lapse Development Eng.	.5938	1.0	.6753	0.85	4.987	244 K	1.0	Baseline w/Lt. Wt. Des.
Cost Development Engine	1.0	1.0	1.0	1.0	4.58	488 K	1.0	Baseline w/ Scaleable Cost
Adv. Tech. Eng.	.5938	.7845	.6763	0.85	4.987	690 K	1.42	Adv. Tech. Eng. w/Quiet Prop.
PD379-11 Eng.	.6769	.9184	.7500	0.85	4.987	484 K	1.715	PD379-11 Eng. w/Quiet Prop.

TABLE XXXIX: TURBOPROP TECHNOLOGY DERIVATIVES propeller with no technology advance. For reasons stated previously, the weight factor could not logically be examined without an accompanying change in lapse rate. The weight factor was also considered to require dimensional changes (smaller) that are used to determine the nacelle size and weight. These are also included in Table XXXIX. Factors are shown for the PD370-11 which were used to expedite the evaluation of this engine in the airplane matrix.

All appropriate scaling of the propulsion system has been carried out in the airplane performance computer programs. The installed engines have been scaled to match the airplane thrust requirements with the scaling of engine weight and cost based on factors taken from DDA QCSEE study data and supplemented by a turboprop curve provide by DDA for this study.

7.5.4 Deflected Slipstream Fuel - Conservative Vehicles

Deflected slipstream vehicles have been derived with rubberized T-56 engines for cruise speeds of M 0.50, 0.55, and 0.60 and design cruise altitudes of 6100m, 7620m, and 9140m (20,000, 25,000, and 30,000 feet). This range of cruise speed and altitude was selected to encompass the expected optimum operating points at various fuel prices and field lengths; the derived optima fell within that range with the exception of minimum fuel consumption designs which were indicated to require cruise speeds below M 0.5. Minimum DOC occurred at design speeds above M 0.5 except at the highest fuel price ($1.15/gallon). A design cruise altitude below 6100m (20,000 feet) would have given slightly lower DOC for the longer field-length cases but was not considered as a practical cruise ceiling for a 926km (500 n.m.) mission. Consideration of the weather avoidance capability and flexibility of these configurations for longer-range missions would bias the practical selection of design criteria towards higher altitudes and higher cruise speeds (at modest penalties in fuel and DOC for operation over shorter stage lengths).

Optimum Cruise Altitude

Figure 274 shows mission fuel as a function of design cruise altitude for the T56 powered

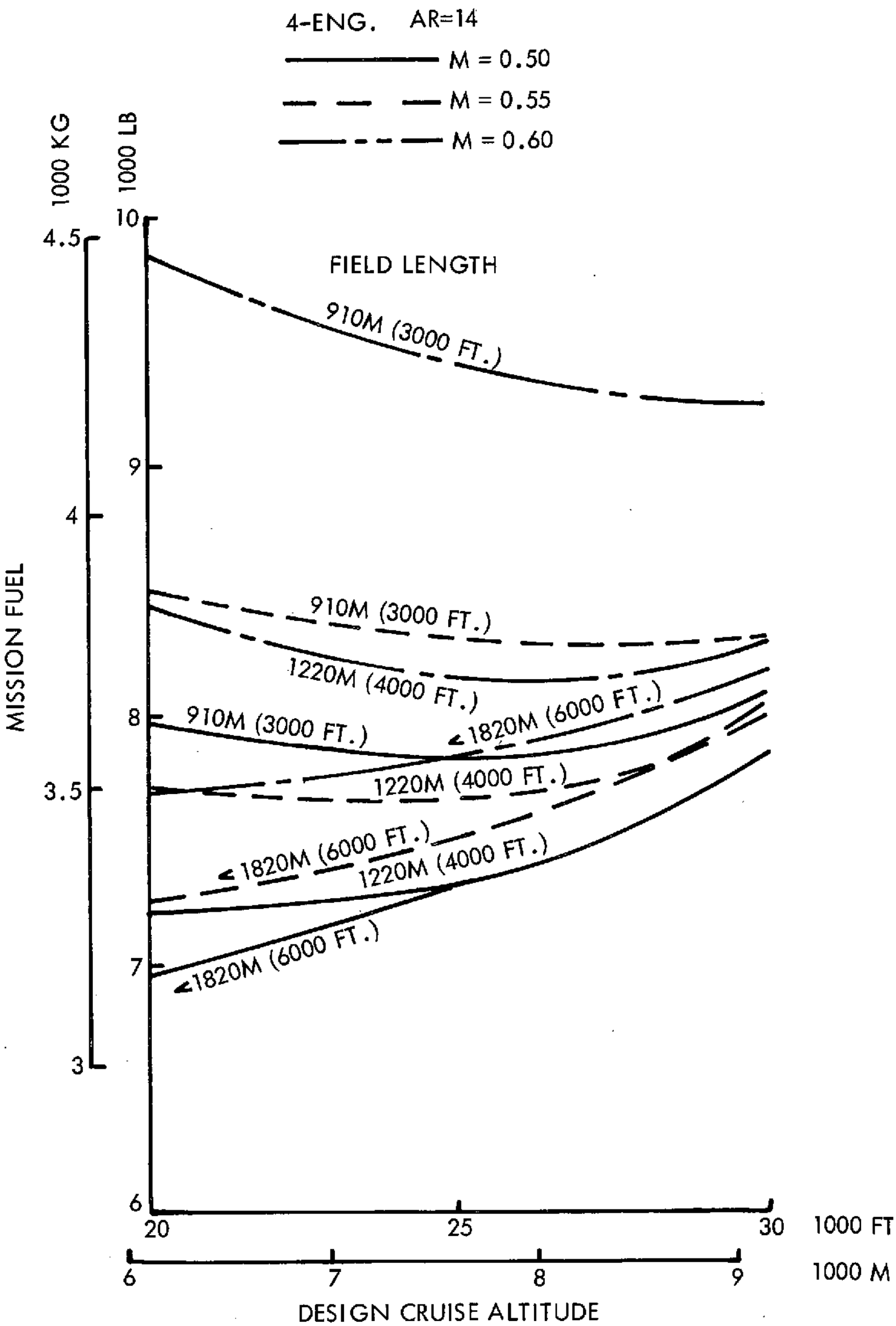


FIGURE 274 T-56 MF MISSION FUEL VS CRUISE ALTITUDE

airplanes. The best altitude for fuel consumption is above 6100m (20,000 ft.) for the 910m (3000 ft) field length designs at all cruise speeds and for the 1220m (4000 ft.) field length designs at cruise speeds of M 0.55 and 0.60. For 1830m (6000 ft.) designs, the minimum cruise altitude analyzed 6100m (20,000 ft.) was best from the standpoint of fuel consumption. Direct operating costs with different fuel prices have been derived and DOC-2 is presented in Figure 275. DOC-1 is lowest at the 6100m (20,000 ft.) design cruise altitude. This effect reflects the influence of lower block time at this altitude in the DOC analysis, overriding the slightly higher fuel consumption when fuel price is low. DOC-2 shows the same minimum at 6100m (20,000 ft.) cruise altitude. At four times the base price (DOC-4), the altitude for minimum fuel begins to reflect an optimum cruise altitude above 6100m (20,000 ft.). At ten times the base fuel cost, the minimum fuel and minimum operating cost conditions are virtually synonymous.

Optimum Cruise Speed

Optimization of cruise speed at the best altitude for the T-56 designs is shown in Figure 276 for minimum fuel consumption. For each field length the best design cruise speed is below M 0.50. However, for minimum DOC-1 the optimum cruise speed is M 0.55 for 910m (3000 ft.) designs and above M 0.60 for 1220m and 1830m (4000 and 6000 ft.) field length designs. This pattern is repeated for DOC-2 (Figure 277), but the increasing effect of fuel price for DOC-4 and DOC-10 overrides the block time benefits of higher speed and brings the optimum cruise speed to M 0.50 or below at high fuel prices.

Data have been added to these figures for the quiet propeller configuration. Comparison with the conventional propeller indicates that at 910m (3000 ft.) field length, the quiet propeller has a considerable advantage in fuel and DOC at all cruise speeds and fuel prices. At 1220m (4000 ft.) field length, the advantage is reduced but is still significant while at 1830m (6000 ft.) the additional static thrust of the quiet propeller is of no advantage and the extra cost (approximately $16,000/engine) due to these propellers results in increased DOC.

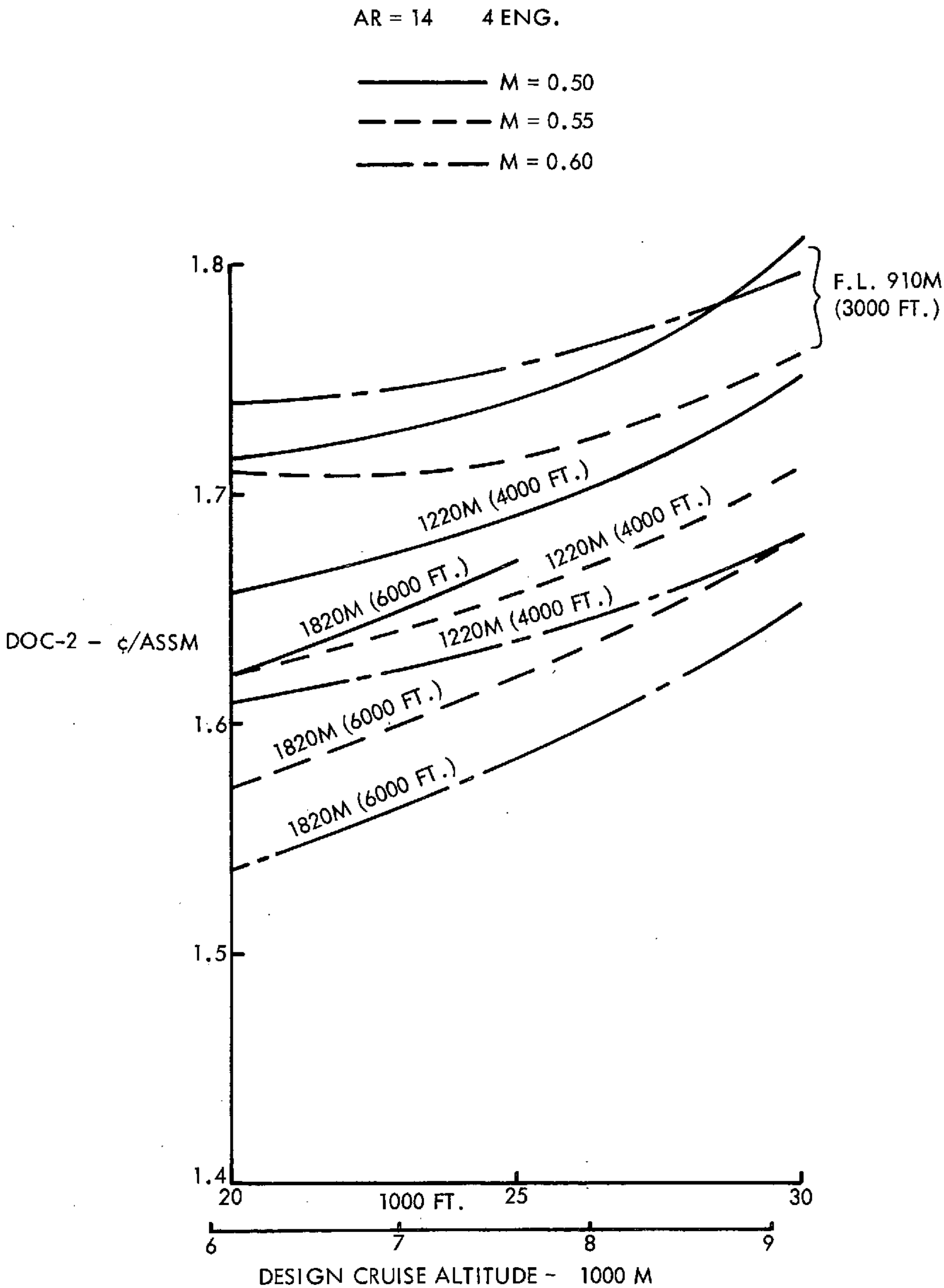


FIGURE 275 T-56 MF DOC-2 VS CRUISE ALTITUDE

4-ENG. AR = 14

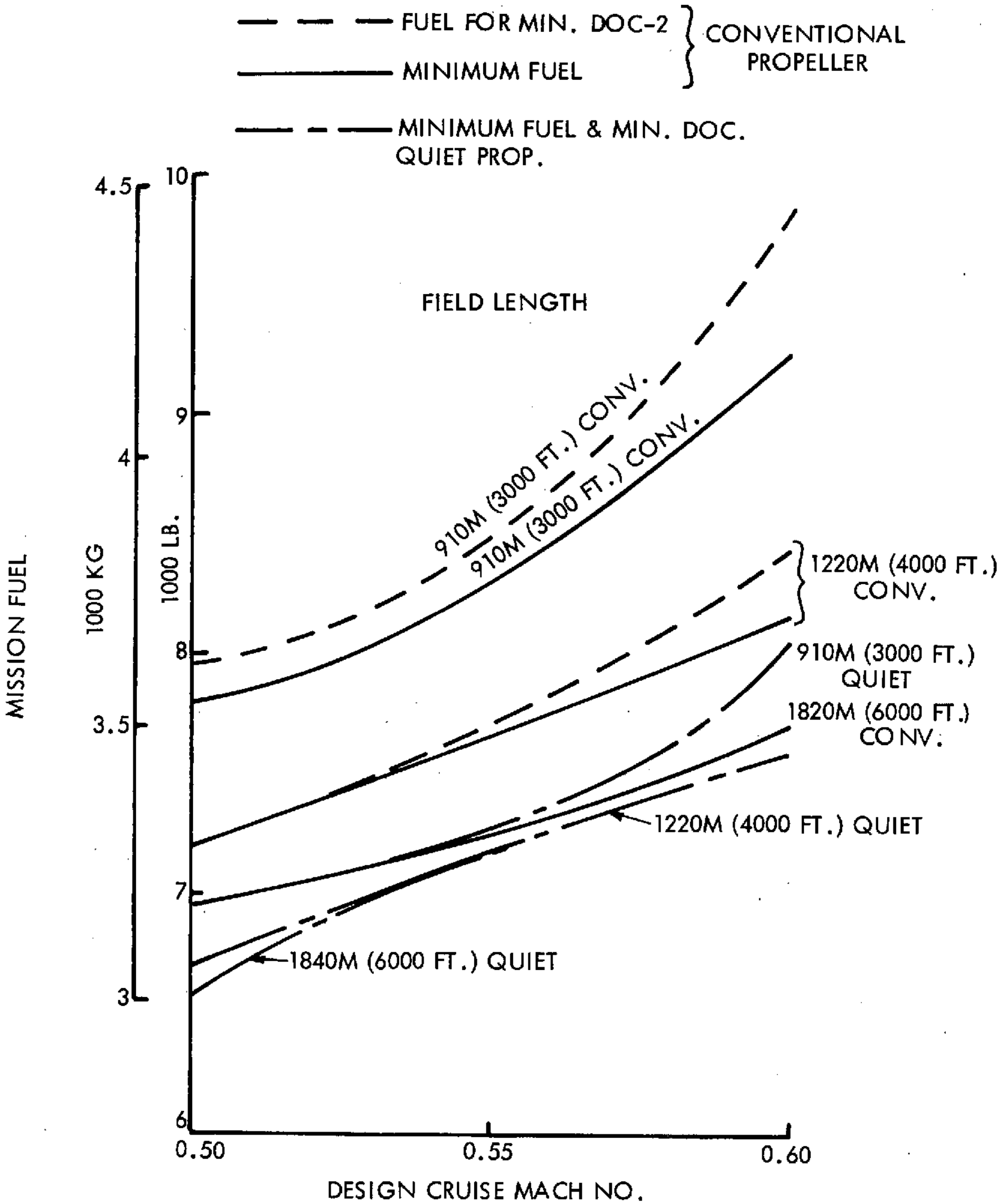


FIGURE 276 T-56 MF MISSION FUEL VS MACH NO

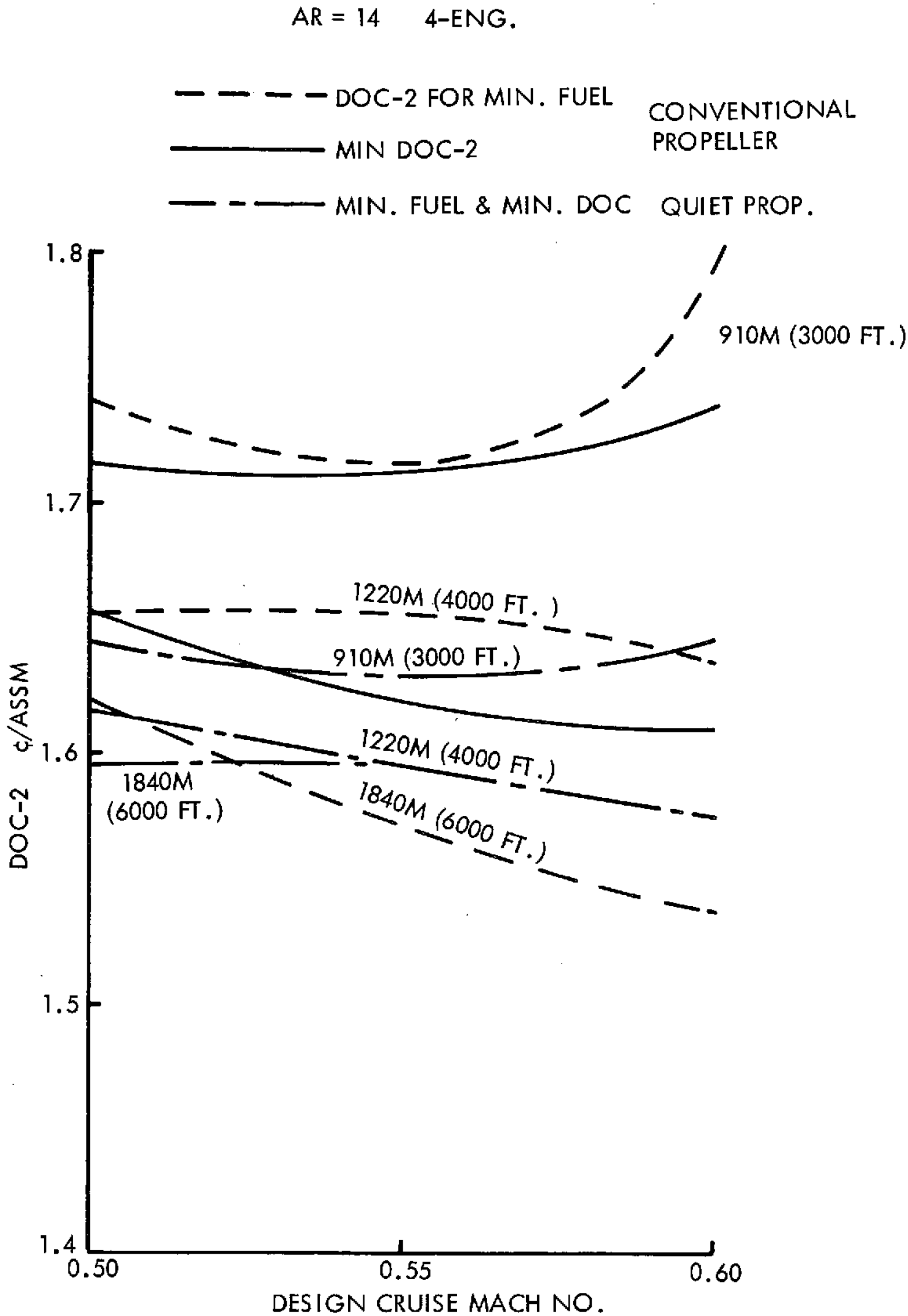


FIGURE 277 T-56 MF DOC-2 VS MACH NO.

Sensitivity

Sensitivity studies have been conducted to determine the effects of:

(1) Improving the engine s.f.c.

(2) Increasing the engine take-off thrust while retaining the engine cruise thrust-to-weight ratio and s.f.c.

(3) Increasing the engine cost.

In addition, the above changes have been combined to represent an advanced technology engine. For comparative purposes, the Detroit Diesel Allison PD370-11 (modified 501 M62) was also evaluated. Table XXXIX contains the factors for weight change, s.f.c. change and lapse change, and dimensions and costs used in determining the above effects. Note that all the cases, including the baseline, incorporate the "quiet" propeller. 0.55M and 910m (3000 ft.) field length were selected for the sensitivity study since this indicated the largest improvement due to the "quiet" propeller and also the minimum DOC at 910m (3000 ft.) field length. The results of the studies are shown in Table XL in terms of mission fuel, DOC-1, -2, -4 , and -10, the subscript indicating the multiplying factor for fuel cost relative to the 1972 price level (11.5¢/gallon). These data have been converted to ratios relative to the baseline which are also included in Table XL.

At 910m (3000 ft.) field length, improvement of the cruise SFC to 78.45% of the T-56 value decreases the mission fuel consumption to 89% of the baseline and decreases DOC -1 to 99.4% and DOC -10 to 93.8% of the baseline. Improvement in takeoff thrust (weight and lapse rate) results in mission fuel being reduced to 97.9% and DOC reduces to 98.8% for DOC-1 and 97.5% for DOC-10. It should be noted that both these cases assume no cost for the introduction of the improvement. Increasing the cost of the engine/propeller combination by a factor of 2.0 results in mission fuel increasing to 103.4% while DOC-1 increases to 112.4% and DOC-10 to 107.3%. It should be noted that these are probably more realistic values for the T-56 and quiet propeller than the baseline for all cases examined since the actual T-56 is too large for these airplanes. Although the baseline engine has been rubberized, the base cost is that of the present production T-56 and this is obviously optimistic.

	3000 Ft.	Pwr	W/S	T/W	Fuel	DOC 1	DOC 2	DOC 4	DOC 10
(1)	Baseline	.8	79.2		7260	1.477	1.629	1.935	2.851
(2)	SFC	.8	80	.295	6460	1.468	1.602	1.87	2.674
	Ratio Rel. to (1)				0.89	0.994	0.983	0.966	0.938
(3)	Take-off Thrust	1.0	80	.3425	7110	1.46	1.604	1.90	2.78
	Ratio Rel. to (1)				0.979	0.988	0.985	0.982	0.975
(4)	Cost	.8	80	.292	7507	1.66	1.815	2.126	3.058
	Ratio Rel. to (1)				1.034	1.124	1.114	1.099	1.073
(5)	Adv. Tech. Eng.	1.0	80	.356	6090	1.68	1.807	2.06	2.82
	Ratio Rel. to (4)				0.811	1.012	0.995	0.969	0.922
(6)	PD370-11	1.0	80	.319	6780	1.522	1.662	1.942	2.782
	Ratio Rel. to (4)				0.903	0.917	0.916	0.913	0.910
	4000 Ft.								
(1)	Baseline	.8	115.1		7170	1.44	1.593	1.892	2.796
(2)	SFC	.8	110	.298	6280	1.43	1.56	1.82	2.60
	Ratio Rel. to (1)				0.876	0.993	0.979	0.962	0.93
(3)	Take-off Thrust	1.0	117	.36	6880	1.42	1.56	1.84	2.68
	Ratio Rel. to (1)				0.960	0.986	0.979	0.973	0.959
(4)	Cost	.8	115	.297	7270	1.61	1.76	2.06	2.96
	Ratio Rel. to (1)				1.014	1.118	1.105	1.089	1.059
(5)	Adv. Tech. Eng.	1.0	117	.362	5890	1.635	1.75	2.00	2.73
	Ratio Rel. to (4)				0.810	1.016	0.994	0.971	0.922
(6)	PD370-11	1.0	117	.324	6570	1.48	1.617	1.884	2.692
	Ratio Rel. to (4)				0.904	0.919	0.918	0.915	0.909

TABLE XL: T-56 SENSITIVITIES; QUIET-PROP; 4 ENG.; M = 0.55; H - 25,000 FT.

When considering the advanced technology and the PD370-11 engines, it is appropriate to compare the results with T-56 airplanes having the 2.0 cost factor included. The ratios in the table do this and indicate that the advanced technology engine has lower mission fuel consumption but due to higher cost does not pay-off in DOC at a fuel price of 11.5¢/gallon. However, at fuel prices of 23¢/gallon and above, the DOC is better than the T-56. The PD370-11 has improved consumption and improved DOC throughout the fuel price range when compared to the doubled engine-cost T-56 data.

7.6 EBF/OTW/DEFLECTED SLIPSTREAM NOISE

Except for the noise analysis of Ref. 1, no detailed noise analyses of the alternate lift concepts discussed in this section have been performed. In lieu of such analyses, an appraisal of the noise characteristics of the more significant among them (relative to the vehicles discussed in details in Sections 4, 5 and 6) is presented in the following paragraphs:

- EBF Noise - the noise level of the EBF aircraft with 1.25 FPR engines defined in Table XXXVI has been changed from the levels shown in Reference 2 (Section 2.8.2.2) by the use of nacelles with wall treatment only. This change makes the fan noise approximately the same level as the flap interaction noise. No detailed analysis has been conducted but it is estimated that the noise characteristics of the aircraft will be approximately the same as those of the OTW/IBF aircraft with 1.35 FPR engines.

- OTW Noise - The use of 1.35 FPR engines with wall treatment in the over-the-wing configuration is expected to give about the same aircraft noise characteristics as the OTW/IBF configuration. The slot jet in the OTW/IBF aircraft contributes insignificantly to the total noise. Differences between the OTW and OTW/IBF will be principally those caused by difference in total installed thrust and differences in climb gradient.

- Deflected Slipstream Noise - Community noise data were analyzed in considerable detail for C-130 aircraft with T-56 turboprop engine in connection with studies of this airplane for Eastern Air Lines and American Airlines. Noise measurements have been made with the current 4.1 m. (13.5 foot) diameter propellor which showed a maximum 152 m. (500-foot) sideline level of 106 PNdB. Noise levels with the quiet propellor [4.9 m. (16 ft.) diameter, tip speed 194 m./sec. (635 fps)] have been subject to detailed analysis in these earlier studies and a prediction of 95 PNdB at 152 m. (500 feet) has a high confidence level. Although no detailed contour data have been obtained it is estimated that the aircraft in the current study will have noise characteristics similar to those of the mechanical flap aircraft with 1.35 FPR engines.

8.0 EVALUATION OF AIRCRAFT CONFIGURATIONS

8.1 DESIGN FOR FUEL CONSERVATION

Sections 4.5, 5.5, 6.5, and 7.0 have presented the results of the studies conducted for the individual concepts; this section compares the concepts and engines, and the relative importance of the various design parameters on the optimization of vehicles for fuel conservation. The previous sections described the effects of cruise speed, cruise altitude, aspect ratio, and field length on the mission fuel consumption and DOC (at various fuel prices) for configurations powered by different fan pressure ratio engines.

Before proceeding to compare the engines and concepts, the magnitude of the fuel savings that are available and their effect on the economic operation of the vehicle may be considered by reference to Figure 278 . An OTW/IBF vehicle designed for minimum DOC at 1972 fuel prices would be powered by two engines and would cruise at 0.8M. Its fuel consumption would be 5900 Kg (13,000 lb.) for the 926Km (500 n.m.) mission and its DOC at 1972 fuel prices would be 1.62¢/ASSM. An alternate vehicle with four engines could have been designed and would have resulted in a 16% reduction in fuel consumption but would have incurred a 1.5% increase in DOC. It would, however, have been a good decision to select the 4-engine vehicle with the higher DOC-1 since the recent increase in fuel price results in the DOC-2 of this configuration being 1.3% lower than that of the 2-engined configuration.

If the airplane had been designed for minimum fuel consumption, the design cruise Mach number with 4 engines would have been 0.6M and the fuel consumption 4080 Kg (9000 lb.), a saving of 31%. The DOC-1 would have increased to 1.75¢/ASSM, an increase of 8 %; the penalty at DOC-2 is still 2.6%. If the airplane had been optimized for DOC at the increased fuel price, a 4-engined, 0.73M configuration would have been selected. The fuel saving relative to the original 2-engined DOC-1 design would still be 27% and the DOC-2 would be actually 4% lower than the original design and 6% lower than the minimum fuel design. Thus it can be seen that by optimizing for the increased cost of fuel, large fuel savings can be achieved while still minimizing operating cost. To achieve the maximum fuel saving creates too large a penalty on DOC and results in cruise speeds which are probably unacceptably low.

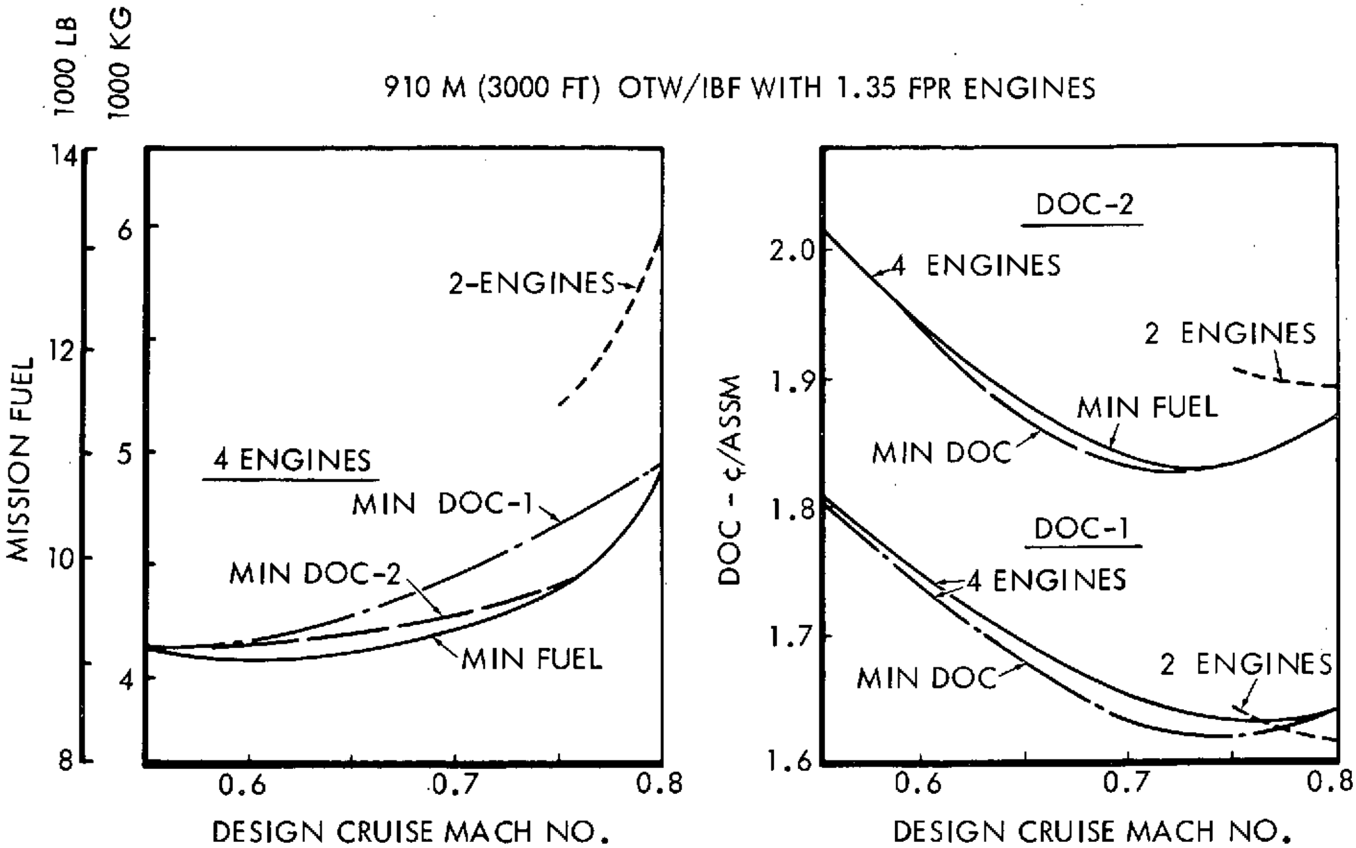


FIGURE 278 EFFECT OF DESIGN CRUISE SPEED

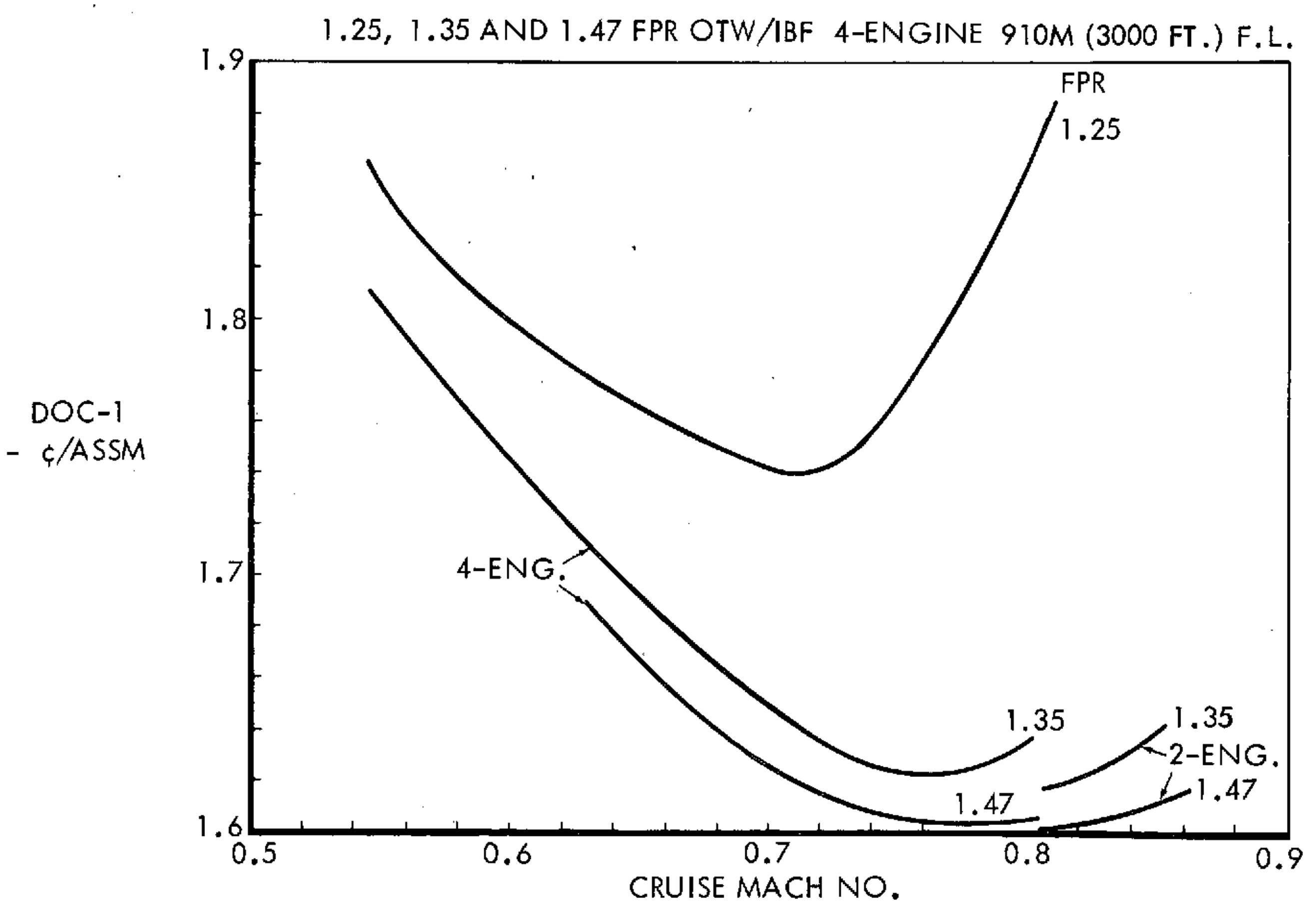


FIGURE 279 DOC-1 VS CRUISE MACH NO. (OTW/IBF)

8.1.1 Effect of Fan Pressure Ratio (FPR)

OTW/IBF Configuration - Examination of the OTW/IBF data for the three FPR's studied; namely, 1.25, 1.35, and 1.47 shows that optimizing airplanes for high-speed with the 1.25 and 1.35 FPR engines automatically provides a relatively short field length, suitable for STOL operation. This is not the case with the 1.47 FPR configurations which can be optimized for 0.8M and 1830m (6000 ft.) field length. In the case of the 1.25 FPR engine, the 0.8M configuration was cruise sized and could not be sized with field lengths greater than 640m (2100 ft.); in the 1.35 FPR case, the 0.8M configuration could not be optimized with field lengths longer than 910m (3000 ft.) because of the cruise requirement. This restriction in sizing flexibility is due to the high lapse rate with altitude of these low fan pressure ratio engines, requiring high values of static thrust to provide adequate cruise thrust at high speed. At lower Mach numbers the thrust required to cruise is lower and it is possible to match the configurations to longer field lengths.

As shown later in this section, the OTW/IBF hybrid concept is only significantly superior to the MF concept in terms of mission fuel and DOC at field lengths of 910m (3000 ft.) or less; the OTW/IBF data for the different FPR engines are therefore only compared at these field lengths.

Figure 279 illustrates the superiority of the 1.47 FPR engine for airplanes optimized for DOC-1 and not required to meet low noise criteria. The 2-engined 1.47 and 1.35 FPR configurations are slightly superior to their 4-engined counterparts at the high Mach numbers where the buckets occur in the DOC. It should be noted that the lower the FPR, the lower the Mach number at which the bucket occurs. Although the 1.25 FPR 2-engined configuration would have lower DOC at the higher Mach numbers than the 4-engined configuration shown, it will not be competitive with the other FPR airplanes. Additionally, reference to Figure 77 shows that doubling the fuel price with the 1.35 FPR engine changes the desired number of engines for minimum fuel or minimum DOC to four. The following paragraphs therefore only compare 4-engine configurations.

Figure 280 presents mission fuel for airplanes optimized for minimum fuel, and DOC-2 for airplanes optimized for minimum DOC-2 plotted against design cruise Mach number.

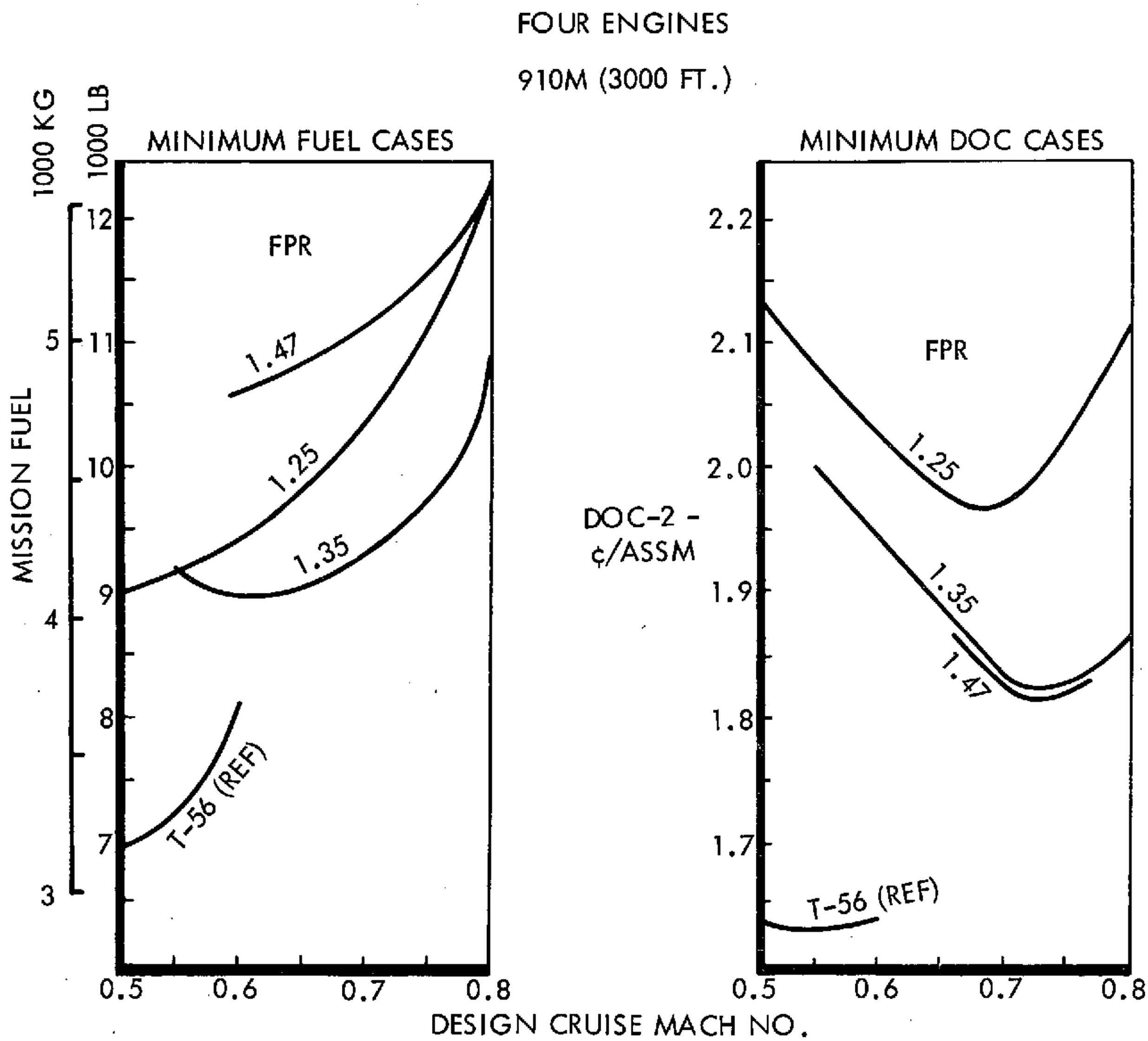


FIGURE 280 FUEL AND COST EFFECTS OF ENGINES AND SPEED - OTW/IBF

C. 4

It is quite apparent that the 1.35 FPR designs provide much better fuel consumption than either the 1.25 or 1.47 FPR configurations over the desirable range of Mach numbers. It should be noted that the best fan engined design still consumes much more than the T-56 turboprop designs at the lower Mach numbers.

The designs optimized for DOC-2 show the 1.47 FPR configurations to be slightly better than the 1.35 FPR and both of them to be definitely superior to the 1.25 FPR vehicles. Again, although its cruise speed is low, the T-56 provides better DOC than any of the fan-powered designs.

As shown earlier in the report, increase in fuel price reduces the design cruise Mach number for minimum DOC. Similarly, changes in fuel price modify the choice of FPR for minimum DOC as shown in Figure 281 .

Minimum DOC-1 is provided as shown earlier by a 1.47 FPR design at 0.8M while DOC-2 is optimized at 1.38 FPR and 0.73M; DOC-4 at 1.35 FPR and 0.7M; and DOC-10 at 1.27 FPR and 0.68M. The curves are relatively flat near the optima and it can be concluded that 1.35 FPR would be an excellent choice for fuel prices of 2 to 10 times the 1972 price level.

MF Configurations - In the case of the MF concept, airplanes could be optimized for high-speed and both STOL and CTOL field lengths for all FPR examined. Due to the low wing loadings encountered, field lengths shorter than 910m (3000 ft.) were not considered for this concept. Additionally, as will be shown later in this section, the MF concept is only competitive or better than the OTW/IBF concept at field lengths longer than 914m (3000 ft.).

Figure 282 presents mission fuel for airplanes optimized for minimum fuel, and for airplanes optimized for minimum DOC-2 plotted against design cruise Mach number. The data are presented in the figure for a 1220m (4000 ft.) field length, which is an excellent choice for this concept since it provides an acceptably high wing loading and

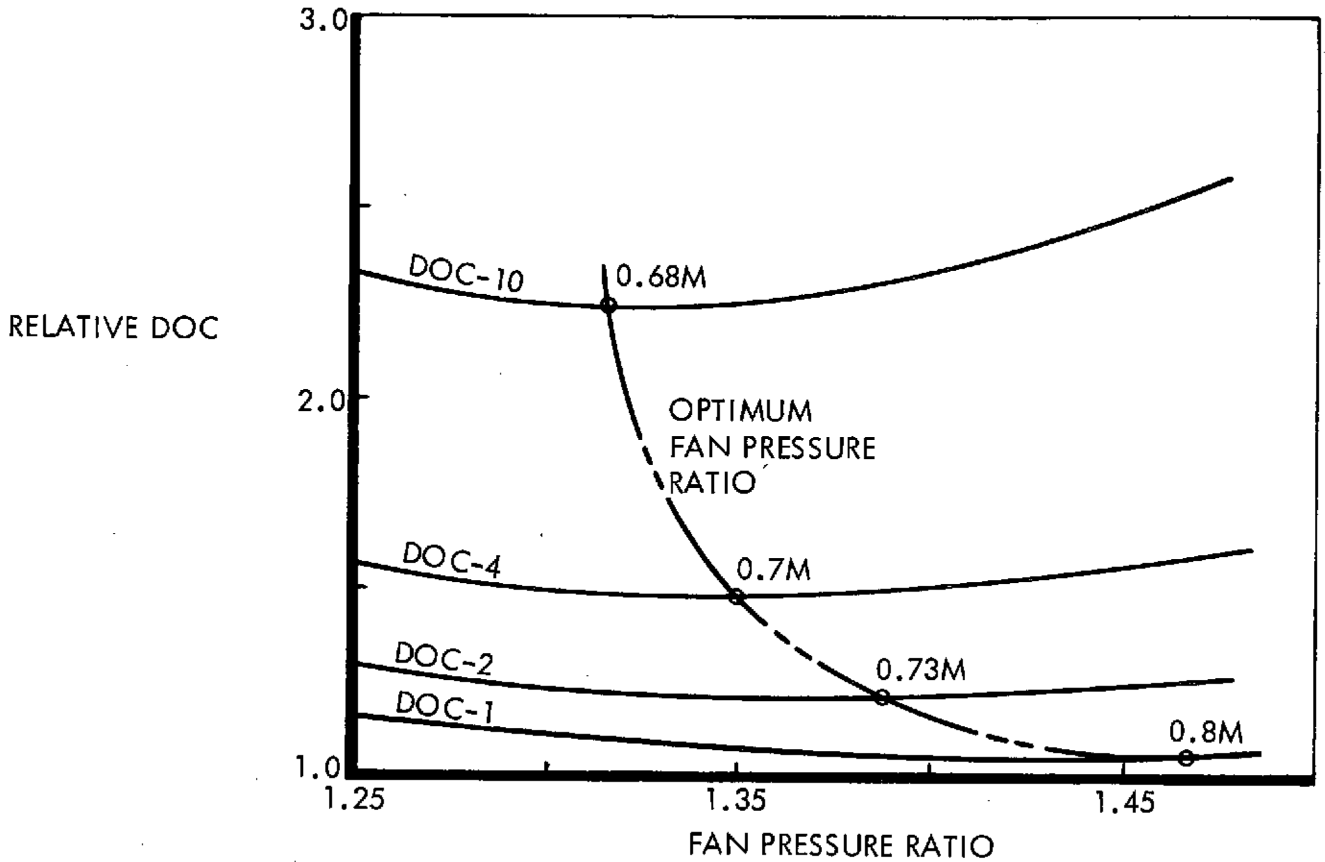


FIGURE 281 EFFECT OF FUEL COST ON OPTIMUM FAN PRESSURE RATIO - OTW/IBF

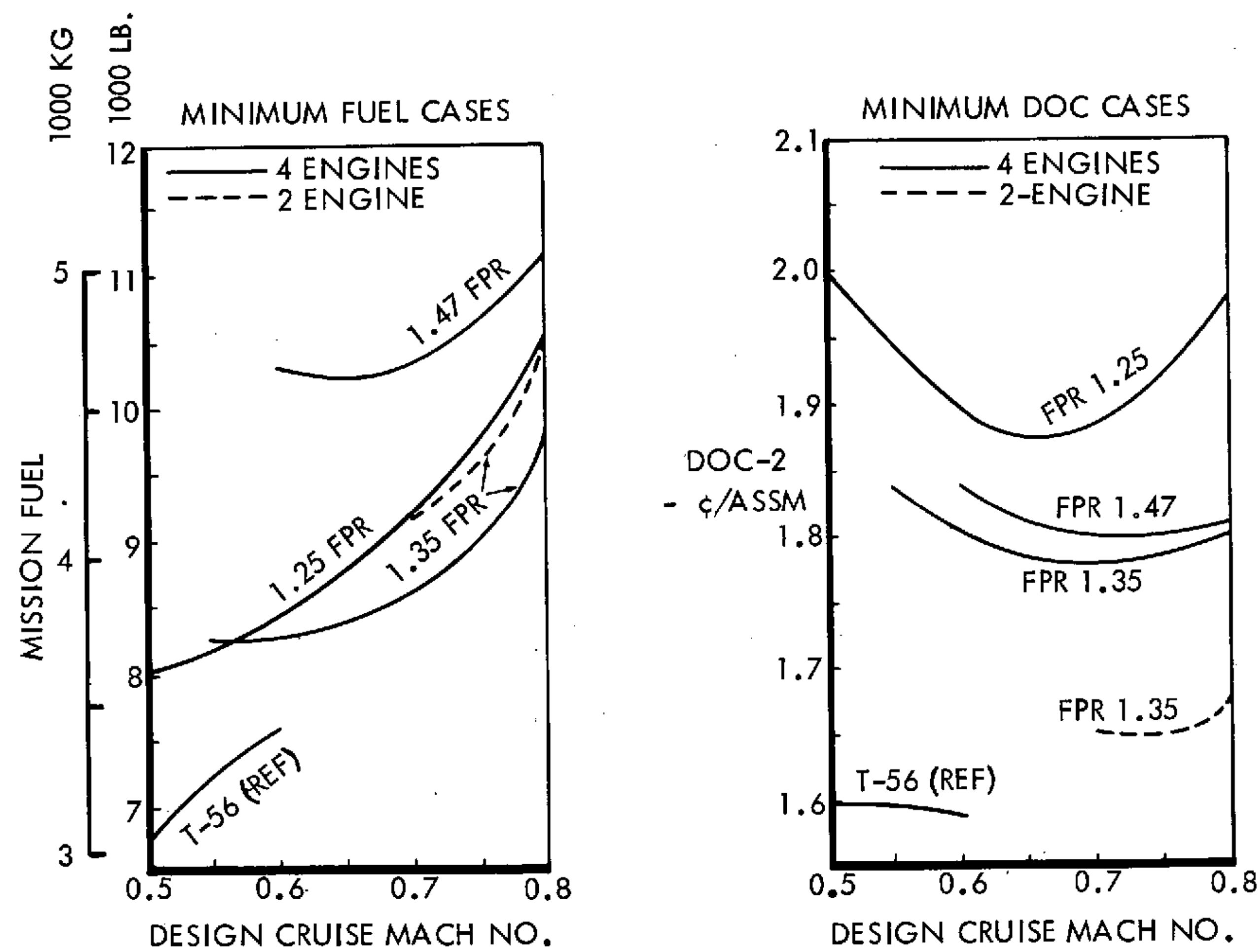


FIGURE 282 FUEL AND COST EFFECTS OF ENGINES AND DESIGN CRUISE SPEED: MF 1220M (4000 FT.)

is superior in both fuel consumption and DOC to the alternate concepts. As for the OTW/IBF, the 4-engined 1.35 FPR designs provide minimum fuel consumption. However, minimum DOC-2 is provided by 2-engined designs compared to 4-engined designs for the OTW/IBF and the 1.35 FPR is shown to be superior to the 1.47 FPR. Throughout the Mach number range studied, again, the 1.25 FPR is not competitive. At DOC-1 the 1.47 FPR is slightly superior to the 1.35 FPR.

The reason the 2-engined configuration is optimum for the MF is due to the landing and cruise criticality, setting the wing loading and thus prohibiting any advantages associated with higher wing loadings that could have been achieved by the better takeoff performance of the 4-engined configurations. At higher fuel prices (DOC10) the lower fuel consumption of the 4-engined configurations offsets the engine-price advantage of the two-engined configurations and the 4-engined configurations are then optimum. The reason the 1.35 FPR is better than the 1.47 is again due to the landing criticality limiting the use of part-power in cruise as a means of obtaining a higher wing loading and better economy. Part-power techniques are an advantage to the low-lapse-rate engines such as the 1.47 FPR but cannot be fully exploited once the airplane reaches its maximum allowable wing loading.

The effect of fuel price and field length on the choice of FPR for optimum DOC is shown in Figures 283 and 284 . At 1220m (4000 ft.) DOC-1 optimizes at 0.75M with a 1.45 FPR design while DOC-10 optimizes at 0.65M with a 1.35 FPR design. At 1830m (6000 ft.) DOC-1 optimizes at slightly higher than 0.75 and 1.48 FPR while DOC-10 optimizes at slightly higher than 0.65M and 1.36 FPR. Thus if low-noise is not the dominating factor in selecting FPR then a 1.39 FPR engine would appear to be a good choice for optimizing MF configurations for increased fuel prices of 2 to 10 times 1972 levels.

8.1.2 Comparison of Concepts

From the foregoing discussion of the effects of fan pressure ratio, it can be concluded that of the three pressure ratios studied, the most suitable for future MF and OTW/IBF fuel conservative airplanes is the 1.35 FPR. This conclusion is further strengthened when noise criteria are considered (Section 8.2). The MF and OTW/IBF concepts are therefore

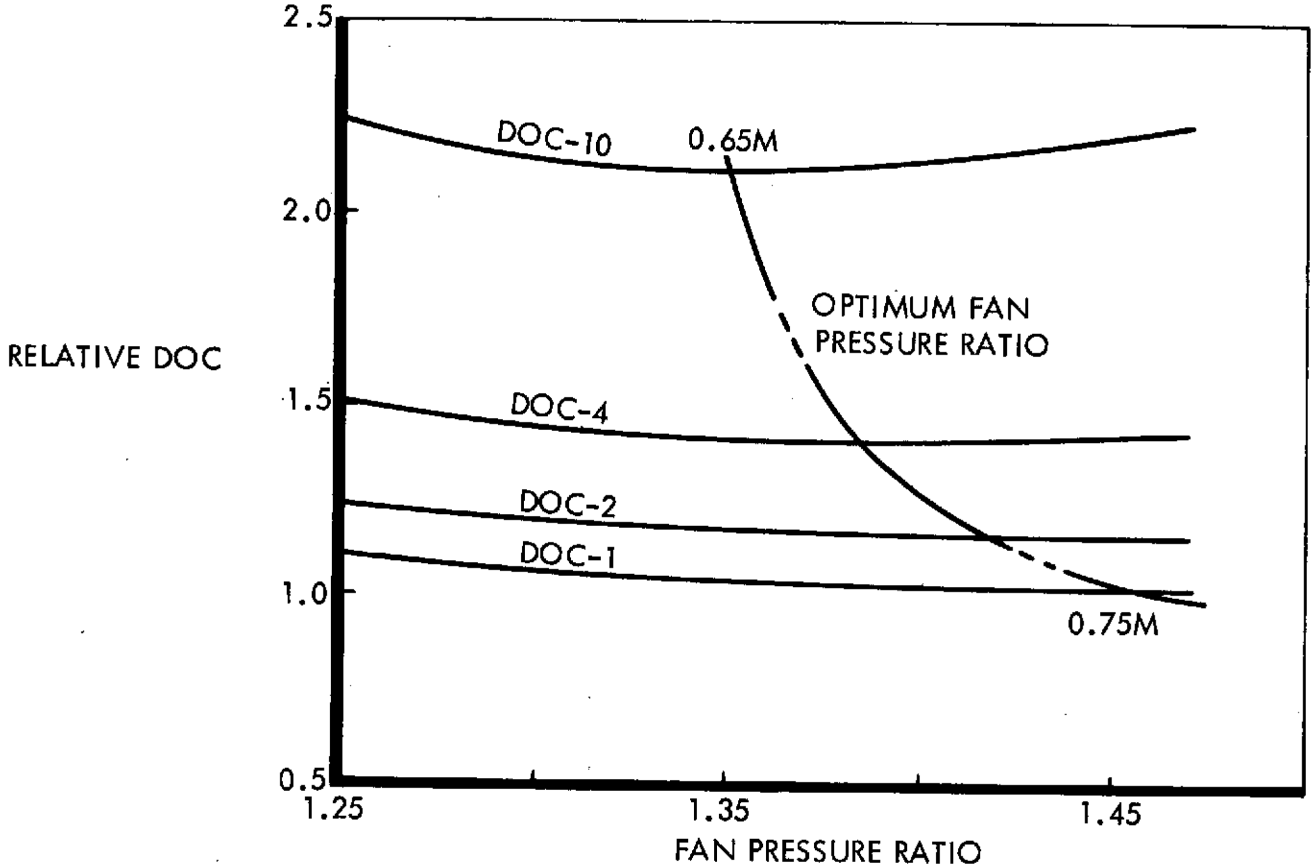


FIGURE 283 EFFECT OF FUEL PRICE ON OPTIMUM FAN PRESSURE RATIO 1220M (4000 FT.) MF

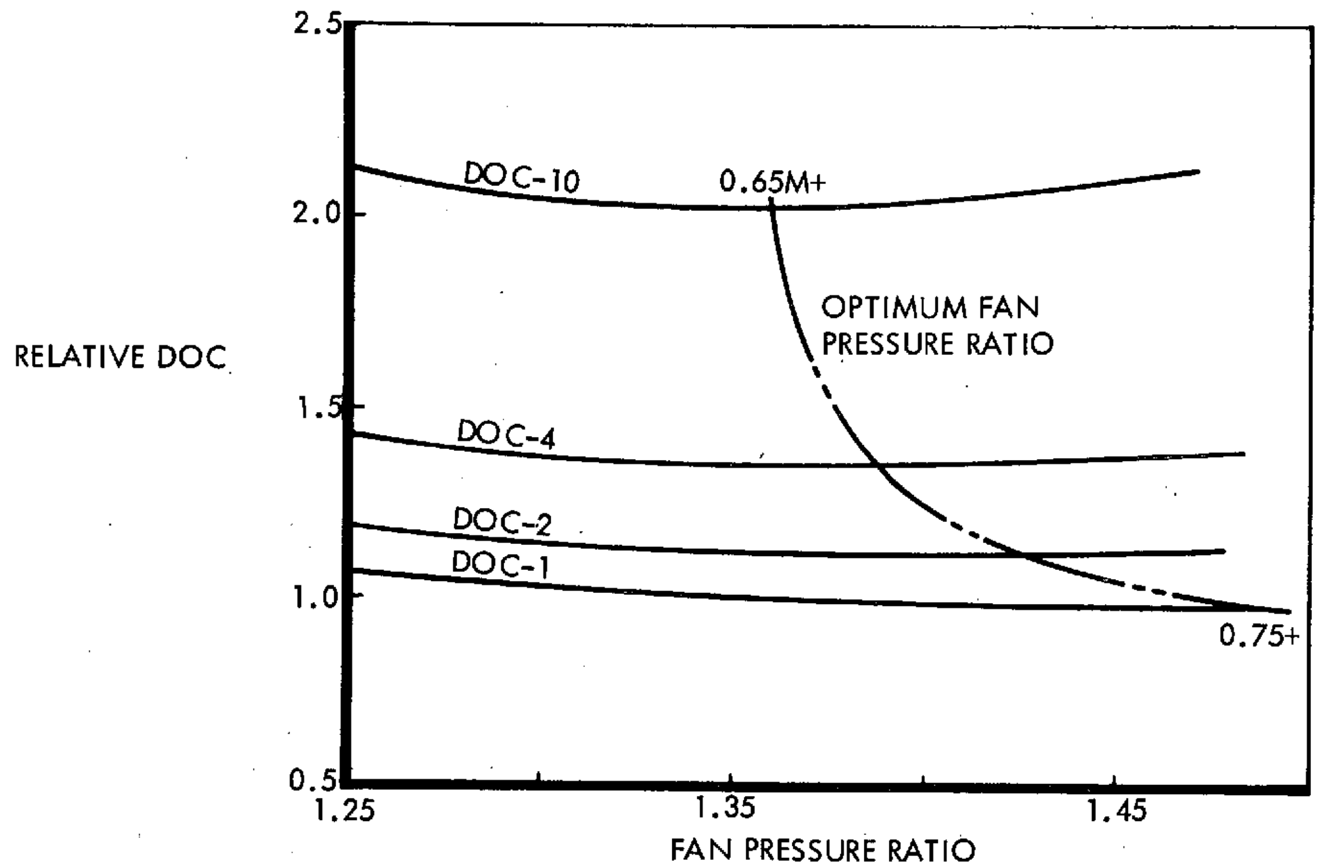


FIGURE 284 EFFECT OF FUEL PRICE ON OPTIMUM FAN PRESSURE RATIO
1830M (6000 FT.) MF

compared at 1.35 FPR while the other concepts are compared with engines which will provide similar noise levels and for which performance and noise data are available. The EBF concept has an additional noise increment due to flap interference effects which makes it necessary to use a lower FPR (1.25). The AW concept used in the comparison is that providing the best economy; namely, the 2-engine design with two load compressors for flap blowing.

Figure 285 presents mission fuel as a function of field length for 2- and 4-engined MF and OTW/IBF designs optimized for DOC-2. The 4-engined OTW/IBF is clearly superior in fuel consumption at field lengths shorter than 1070m (3500 ft.) while the 4-engined MF is superior at field lengths longer than 1220m (4000 ft.). It should be noted, however, that the 2-engined MF provides a lower DOC than the 4-engined configuration and therefore the primary comparison should be between the 4-engined OTW/IBF and the 2-engined MF.

The direct operating costs of these two concepts are compared in Figure 286 at two fuel price levels. At 910m (3000 ft.) the MF is slightly superior to the OTW/IBF at DOC-1 but at DOC-2 the concepts have almost identical costs. It must be noted that in both cases, DOC-1 and DOC-2 the optimum MF is 0.05M slower than the OTW/IBF. If both concepts are designed for the same Mach number, the OTW/IBF is slightly better than the MF.

The economics of the two concepts are so similar that the selection of one or the other for 910m (3000 ft.) field length operation must be based on some other criterion, such as ride quality, simplicity or fuel economy. Tables XLI and XLII present characteristics of OTW/IBF and MF designs optimized for various fuel prices and minimum fuel consumption for a 910m (3000 ft.) field length. In all cases, the OTW/IBF has a wing loading of not less than 449 Kg/sq.m. (92 lb/sq.ft.) compared with 287 Kg/sq.m. (58.8 lb/sq.ft.) for the MF. The unaugmented ride quality of the OTW/IBF will be noticeably better than the MF. For the MF to be acceptable a gust alleviation system must be developed and incorporated as discussed in Section 6.7. It is notable that the configuration of the MF vehicle when optimized for DOC-10 or minimum fuel consumption changes to a 4-engine

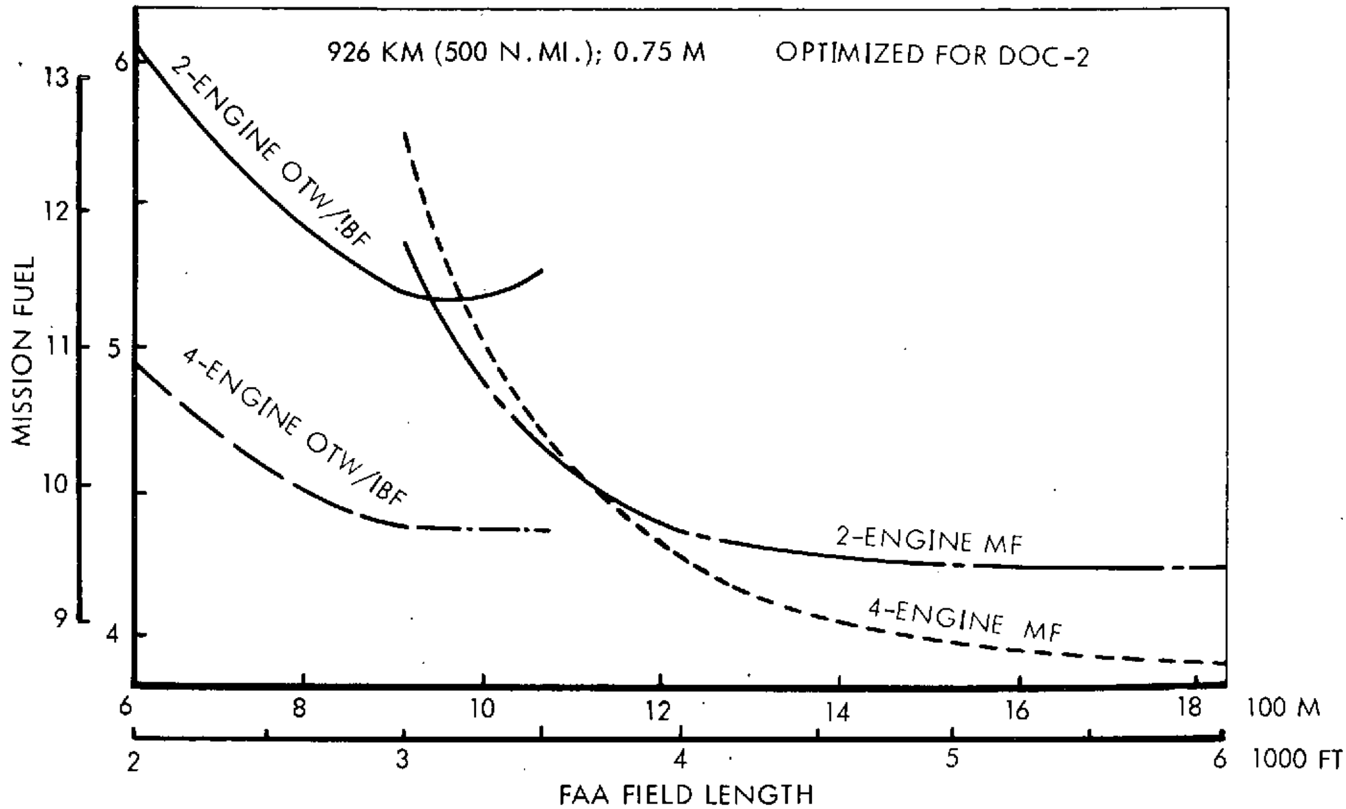


FIGURE 285 EFFECT OF FIELD LENGTH ON MISSION FUEL

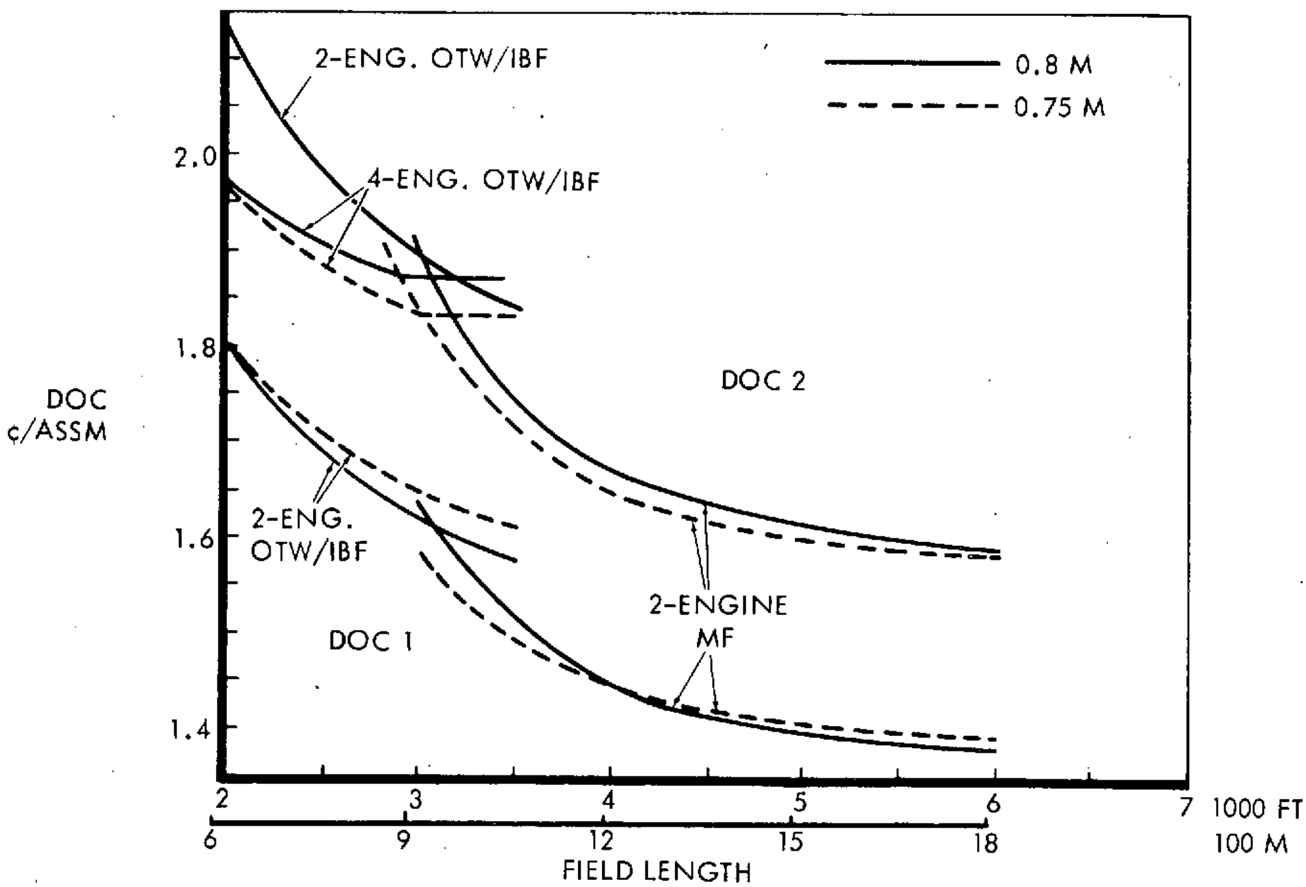


FIGURE 286 EFFECT OF FIELD LENGTH ON DOC

	REF. 2 1.32 FPR V.P. DOC-1	OPTIMIZED FOR DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.70	0.60
NO. OF ENGINES	2	2	4	4	4	4
OWE - KG	44,570	43,450	36,510	35,290	35,290	34,870
(LB)	(98,250)	(95,790)	(80,490)	(77,800)	(77,800)	(76,880)
GROSS WEIGHT - KG	66,840	65,550	56,450	54,670	54,670	53,910
(LB)	(147,350)	(144,520)	(124,440)	(120,520)	(120,540)	(118,860)
RATED THRUST - KN	163.7	167.5	55.3	48.0	48.0	44.1
(LB)	(36,810)	(37,660)	(12,440)	(10,790)	(10,790)	(9,910)
MISSION FUEL - KG	6,330	6,030	4,400	4,210	4,210	$\boxed{4,070}$
(LB)	(13,960)	(13,300)	(9,700)	(9,290)	(9,290)	(8,975)
AR	7.0	7.73	12	14	14	14
*DOC-1 -- ¢/ASSM.	$\boxed{1.797}$	$\boxed{1.616}$	1.634	1.646	1.646	1.747
DOC-2 -- ¢/ASSM.	-	1.889	$\boxed{1.831}$	1.837	1.837	1.937
DOC-4 -- ¢/ASSM.	-	2.437	2.246	$\boxed{2.221}$	2.221	2.307
DOC-10 - ¢/ASSM.	-	4.08	3.441	3.373	$\boxed{3.373}$	3.422
$W/S_{T.O.}$ - KG/SQ. M.	455	449	554	530	530	457
(LB/SQ.FT)	(93.2)	(92.0)	(113.5)	(108.5)	(108.5)	(93.5)
90 EPNdB T.O. AREA	1.30	1.19	1.53	1.45	1.45	1.40
SQ. KM (SQ. MI)	(0.5)	(0.46)	(0.59)	(0.56)	(0.56)	(0.54)

$\underbrace{\text{DOC-4} \quad \text{DOC-10}}_{\text{IDENTICAL AIRPLANE}}$

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2
1500 IN PRESENT PHASE

TABLE XLI: AIRPLANE CHARACTERISTICS, 1.35 FPR, OTW/IBF, 910M (3000 FT) F.L.

	REF. 2 DOC-1	OPTIMIZED FOR DOC-1	DOC-1	DOC-2	DOC-4	DOC-10	MIN FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.70	0.60	0.55
NO. OF ENGINES	2	2	2	2	2	4	4
OWE - KG	52,590	46,870	41,760	40,020	40,020	38,270	35,290
(LB)	(115,940)	(103,330)	(92,060)	(88,230)	(88,230)	(84,380)	(77,800)
GROSS WEIGHT - KG	76,610	69,000	62,690	60,210	60,210	57,700	54,200
(LB)	(168,890)	(152,110)	(138,200)	(132,740)	(132,740)	(127,210)	(119,480)
RATED THRUST - KN	195.5	151.6	125.3	118.4	118.4	43.4	38.5
(LB)	(43,950)	(34,070)	(28,160)	26,610)	(26,610)	(9,760)	(8,660)
MISSION FUEL - KG	7,550	6,110	5,440	4,870	4,870	4,200	$\boxed{3,980}$
(LB)	(16,640)	(13,460)	(12,000)	(10,730)	(10,730)	(9,250)	(8,770)
AR	7.0	7.0	7.0	7-10	7-10	10	14
*DOC-1 -- ¢/ASSM.	$\boxed{1.931}$	$\boxed{1.632}$	$\boxed{1.582}$	1.597	1.597	1.75	1.828
DOC-2 -- ¢/ASSM.		1.912	1.832	$\boxed{1.818}$	1.818	1.94	2.010
DOC-4 -- ¢/ASSM.		2.472	2.328	2.262	$\boxed{2.262}$	2.32	2.376
DOC-10 -- ¢/ASSM.		4.152	3.760	3.589	3.589	$\boxed{3.46}$	3.472
$W/S_{T.O.}$ - KG/SQ.M.	302	287	287	287	287	287	287
(LB/SQ.FT)	(61.8)	(58.8)	(58.8)	(58.8)	(58.8)	(58.8)	(58.8)
90 EPNdB T.O. AREA	1.04	1.48	1.40	1.37	1.37	1.09	1.06
SQ. KM (SQ. MI)	(0.4)	(0.57)	(0.54)	(0.53)	(0.53)	(0.42)	(0.41)

$\underbrace{\text{DOC-2} \quad \text{DOC-4}}_{\text{IDENTICAL AIRPLANE}}$

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2 1500 IN PRESENT PHASE

TABLE XLII: AIRPLANE CHARACTERISTICS, 1.35 FPR, MF, 910M (3000 FT) F.L.

arrangement. The MF concept is simpler than the OTW/IBF because of the additional work required to design, develop, and prove the OTW/IBF flap, ducting, and nacelle installations. To determine the choice between MF and OTW/IBF at this field length, it is proposed that a gust alleviation system for the MF be demonstrated and that an OTW/IBF research airplane be developed.

If the T-56 turboprop deflected slipstream concept is acceptable from passenger appeal and cruise speed considerations, it provides better fuel consumption and DOC than either the MF or OTW/IBF at this field length as shown in Figure 287 and Table XLIII. Also shown in Figure 287 are the EBF and AW concepts. The EBF, powered by the 1.25 FPR fan for noise considerations cruises at 0.65M and therefore has acceptably low fuel consumption but its DOC values are then unacceptably high. The AW concept has high fuel consumption and a high DOC even though this particular concept cruises with 1.35 FPR engines and only uses the FPR 3.0 load compressors in STOL terminal operations. The alternate AW concepts using FPR 3.0 to 3.2 engines for cruise and flap blowing have even greater fuel consumption and higher operating costs.

At field lengths shorter than 910m (3000 ft.) the MF rapidly deteriorates in economy and ride quality and the choice lies then between the OTW/IBF, EBF, and AW concepts. Figure 287 shows the OTW/IFB to have better fuel consumption and DOC-2 than the other concepts at 660m (2000 ft.) field length and is therefore the recommended concept.

At field lengths longer than 910m (3000 ft.), Figure 287 shows the MF to have the best operating cost at DOC(2) and good fuel economy. Table XLIV summarizes the characteristics of the MF airplanes optimized for different fuel price levels and minimum fuel consumption, and a field length of 1220m (4000 ft.). At this field length the wing loading is shown to be sufficiently high that ride quality will be acceptable, and the MF concept is recommended as the best fan-powered concept. Again, it should be noted from Figure 287 that the T-56 deflected slipstream airplane at 1220m (4000 ft.) has by far the lowest fuel consumption and the lowest DOC-2. At field lengths longer than 1640m (5000 ft.), the fan-powered MF has a lower DOC than the turboprop.

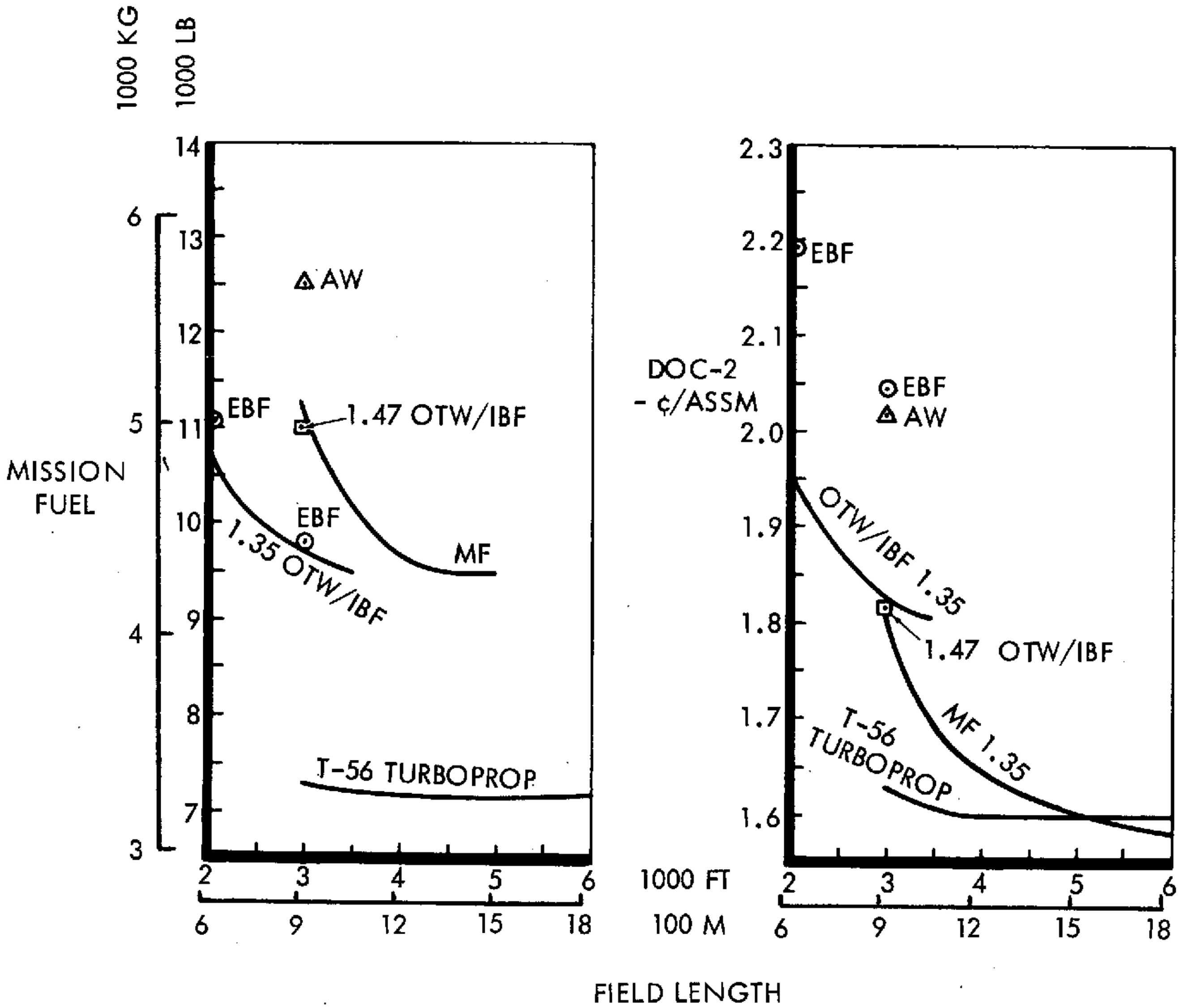


FIGURE 287 COMPARISON OF CONCEPTS - MINIMUM DOC-2 CASES

	OPTIMIZED FOR				
	DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.60	0.55	0.55	0.50	0.50
NO. OF ENGINES	4	4	4	4	4
OWE - KG	35,690	34,805	34,805	34,360	34,360
(LB)	(78,680)	(76,730)	(76,730)	(75,750)	(75,750)
GROSS WEIGHT - KG	54,440	53,170	53,170	52,720	52,720
(LB)	(120,028)	(117,223)	(117,223)	(116,232)	(116,232)
MISSION FUEL - KG	3,656	3,293	3,292	3,148	$\boxed{3,148}$
(LB)	(8,060)	(7,260)	(7,260)	(6,940)	(6,940)
AR	14	14	14	14	14
DOC-1 -- ¢/ASSM.	$\boxed{1.473}$	1.477	1.477	1.500	1.500
DOC-2 -- ¢/ASSM.	1.642	$\boxed{1.629}$	1.629	1.643	1.643
DOC-4 -- ¢/ASSM.	1.977	1.935	$\boxed{1.935}$	1.935	1.935
DOC-10 -- ¢/ASSM.	2.985	2.851	2.851	$\boxed{2.805}$	2.805
$W/S_{T.O.}$ - KG/SQ.M.	391	387	387	371	371
(LB/SQ.FT)	(80.0)	(79.2)	(79.2)	(76.0)	(76.0)
INST. THRUST/ENG. - KN	40.1	37.8	37.8	35.6	35.6
(LB)	(9,019)	(8,502)	(8,502)	(7,996)	(7,996)
CRUISE POWER %	90	80	80	70	70
90 EPNdB AREA - SQ. KM	1.30	1.30	1.30	1.30	1.30
(ESTIMATE) (SQ. MI)	(0.5)	(0.5)	(0.5)	(0.5)	(0.5)
		IDENTICAL AIRPLANE		IDENTICAL AIRPLANE	

TABLE XLIII: T-56 AND QUIET PROPELLER - 910 M (3000 FT) F.L.

	REF. 2 DOC-1	OPTIMIZED FOR DOC-1	DOC-2	DOC-4	DOC-10	MIN. FUEL
MACH NO.	0.8	0.8	0.75	0.70	0.65	0.60
NO. OF ENGINES	2	2	2	2	4	4
OWE - KG	40,510	39,140	36,770	35,790	33,800	33,920
(LB)	(89,300)	(86,280)	(81,060)	(78,900)	(74,520)	(74,770)
GROSS WEIGHT - KG	62,120	59,400	56,460	55,340	52,590	52,530
(LB)	(136,950)	(130,950)	(124,480)	(122,000)	(115,950)	(115,800)
RATED THRUST - KN	150.3	114.3	111.0	104.8	40.9	38.0
(LB)	(33,800)	(25,690)	(24,950)	(23,560)	(9,190)	(8,550)
MISSION FUEL - KG	5,865	4,717	4,382	4,218	3,801	$\boxed{3,715}$
(LB)	(12,930)	(10,400)	(9,660)	(9,300)	(8,380)	(8,190)
AR	7.0	10.0	10.0	10.0	14.0	14
*DOC-1 -- ¢/ASSM.	$\boxed{1.681}$	$\boxed{1.446}$	1.45	1.466	1.626	1.70
DOC-2 -- ¢/ASSM.		1.67	$\boxed{1.648}$	1.659	1.798	1.87
DOC-4 -- ¢/ASSM.		2.10	2.05	$\boxed{2.044}$	2.142	2.21
DOC-10 -- ¢/ASSM.		3.408	3.25	3.20	$\boxed{3.174}$	3.23
$W/S_{T.O.}$ - KG/SQ.M.	455	391	393	379	403	361
(LB/SQ.FT)	(93.1)	(80.0)	(80.5)	(77.6)	(82.5)	(74.0)
90 EPNdB T.O. AREA	0.97	1.42	1.37	1.32	1.088	N/A
SQ. KM (SQ. MI)	(0.375)	(0.55)	(0.53)	(0.51)	(0.42)	

* ENGINE PRODUCTION QUANTITY: 750 IN REF. 2
1500 IN PRESENT PHASE

TABLE XLIV: AIRPLANE CHARACTERISTICS
1.35 FPR, MF, 1220 M (4000 FT) F.L.

The mission fuel and DOC-2 values of the recommended airplanes for field lengths of 610m, 910m, 1220m, and 1830m (2000 ft., 3000 ft., 4000 ft., and 6000 ft.) are summarized in Table XLV.

500 N. MI. (926M) STAGE LENGTH; 148 PASSENGER AIRCRAFT

NOISE LEVEL: 95 TO 100 EPNdB AT 500 FT. (152M) SIDELINE (FAR 36 MINUS 15 TO 20 dB)

AIRCRAFT OPTIMIZED FOR MINIMUM DOC AT 2 X FUEL PRICE (DOC-2)

FIELD LENGTH FT. (M)	BEST FAN-POWERED AIRCRAFT - M 0.75			TURBO-PROP - M 0.55	
	LIFT CONCEPT (NO. ENGINES)	DOC-2 ¢/ASSM	MISSION FUEL LB (KG)	DOC-2 ¢/ASSM	MISSION FUEL LB (KG)
2000 (610)	HYBRID OTW/IBF (4)	1.96	10,110 (4586)		
3000 (910)	HYBRID OTW/IBF (4)	1.83	9.700 (4400)	1.63	7,260 (3293)
3000 (910)	MF (2)	1.83	11,810 (5357)		
4000 (1220)	MF (2)	1.65	9,660 (4382)	1.59	7,170 (3252)
6000 (1830)	MF (2)	1.58	9,430 (4277)		
CURRENT CTOL - REF.		(1.6)	13,400 (6078)		

TABLE XLV: SUMMARY OF FUEL CONSUMPTION

8.2 DESIGN FOR NOISE CONSTRAINTS

Previous sections have presented noise data for each of the lift concepts; it is the purpose of this section to summarize and compare these data. Since aircraft and fuel consumption are so strongly affected by constraints such as field performance, cruise speed, block time, and ride quality, in addition to noise, comparisons will be made with combinations of these factors.

Table XLVI summarizes the effect of noise constraints on airplane configuration, DOC-2, and fuel consumption with no restriction on the performance factors. With cruise speed and block time unrestricted, the two-engine mechanical flap aircraft with 1830 m. (6000 foot) field length and FPR 1.35 engines satisfies many noise restrictions with no penalty indicated for DOC-2 or fuel. The turboprop (deflected slipstream) aircraft were not ranked in establishing Table XLVI for the following reasons:

- Detailed noise data were not available for the cases in which it might be best in DOC -- FAR 36-15
  Sperry box
  90 EPNdB footprint areas of 1.3 Km^2 (0.5 sq. mi.) or less
  90 EPNdB footprint lengths of 1.9 Km (1 N.M.) or less

- Application to the high-density mission with significant stage lengths of 926 Km. (500 nautical miles) is not considered a viable application of turboprop aircraft, as discussed in Section 10.

For purposes of further comparisons, the 1830 m. (6000 foot) MF airplane is used as a basis for expressing penalties.

8.2.1 Field Length Restricted to 1220 m. (4000 ft.) or Less

If field lengths for short haul aircraft are restricted to 1220 m. or less, as suggested throughout the study, the penalties for meeting the different potential requirements are those indicated in Table XLVII. Most of the cases are best satisfied with MF aircraft. Significant increases in DOC and fuel penalties are indicated if 90 EPNdB requirements of

	LIFT CONCEPT	NO. ENG.	FPR	FIELD LENGTH M (FT)	CRUISE SPEED	PAX	DOC-2 ¢/ASSM	FUEL KG (LB)
MIN DOC-2 CASE:	MF	2	1.47	1,830 (6,000)	0.75	148	~1.59	—
MIN DOC FOR FAR36-5	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR FAR36-10	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR FAR36-15	MF	2	1.35	1,220 (4,000)	0.75	148	1.641	4,318 (9,519)
MIN DOC FOR 95 EPNdB @ 152 M (500')	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
MIN DOC FOR 80 EPNdB @ SPERRY BOX SIDELINE	OTW/IBF	4	1.25	910 (3,000)	0.75	50	3.87	2,223 (4,900)
MIN DOC FOR 80 EPNdB @ SPERRY BOX FLYOVER	OTW/IBF	4	1.25	610 (2,000)	0.75	5-10	7+	
MIN DOC-2 FOR 90 EPNdB FOOTPRINT:								
2.60 SQ. KM (1 SQ.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
1.3 SQ. KM (0.5 SQ.MI.)	MF (0.526)	2	1.35	1,220 (4,000)	0.75	148	1.641	4,318 (9,519)
.83 SQ. KM (0.32 SQ. MI.)	OTW/IBF (WITH SPLITTERS)	4	1.35	910 (3,000)	0.75	148	1.863	4,790 (10,560)
.75 SQ. KM (0.29 SQ. MI.)	MF	4	1.25	1,220 (4,000)	0.65	148	1.887	4,027 (8,877)
MIN DOC-2 FOR 90 EPNdB FOOTPRINT LENGTH:								
6.48 KM (3.5 N.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
3.704 KM (2.0 N.MI.)	MF	2	1.35	1,830 (6,000)	0.75	148	1.599	4,199 (9,258)
1.85 KM (1.0 N.MI.)	OTW/IBF	2	1.35	< 910 (3,000)	0.75	148	1.90	6,350 (14,000)
1220 M (4000 FT)	OTW/IBF	2	1.25	610 (2,000)	0.75	148	2.3	6,804 (15,000)

TABLE XLVI: DOC AND FUEL PENALTIES – NO PERFORMANCE CONSTRAINTS

	Lift Concept	No. of Engines	Engine FPR	Field Length m	(ft)	Cruise Speed M	DOC 2 Penalty %	Fuel Penalty %
Reference	MF	2	1.35	1830	(6000)	0.75	0	0
FAR 36 - 10 - 15	MF	2	1.35	1220	(4000)	0.75	3.0	4.3
95 EPNdB @ 152m (500 FT.)	MF	2	1.32	1220	(4000)	0.75	4	5
90 EPNdB Footprint								
Area = 2.60 Km^2 (1.00 sq mi)	MF	2	1.40	1220	(4000)	0.75	3	4
1.30 Km^2 (0.50 sq mi)	MF	2	1.33	1220	(4000)	0.75	4	5
0.83 Km^2 (0.32 sq mi)	OTW/IBF	4 Splitler	1.35	910	(3000)	0.75	17	14
0.75 Km^2 (0.29 sq mi)	MF	4	1.25	1220	(4000)	0.65	18	(- 4)
90 EPNdB Footprint								
Length = 1.85 Km (1.0 n.m.)	OTW/IBF	2	1.35	850	(2800)	0.75	20	50
1220m (4000 FT)	OTW/IBF	2	1.25	610	(2000)	0.75	40	60
Sperry Box - 80 EPNdB	Small airplane with low wing loading designed for short stage lengths						400	200 (per passenger)

TABLE XLVII: DOC AND FUEL PENALTIES @ FIELD LENGTH 1220 M (4000 FT) OR LESS

less than 1.0 sq. Km. (0.39 sq. mi.) area, or 2.3 Km. (7500 ft.) for length are imposed. As noted, the 80 EPNdB STOLport requirement designated 'Sperry box' calls for a very small airplane probably designed for low wing loading and short stage lengths. This requirement does not appear compatible with the high density scenario although it may become feasible for commuter operations.

8.2.2 Field Length Restricted to 910 m. (3000 Ft.) or Less

The penalties for different noise requirements with field length restricted to 910 m. are given in Table XLVIII. This comparison was also restricted to designs for M 0.75 cruise speed. The low wing loading mechanical flap aircraft designed to cruise at M 0.70 would be approximately one percent lower in DOC and nine percent better in fuel consumption. It is concluded that most of the prospective noise requirements can be met with 910 m. (3000 ft.) aircraft at a total penalty of 17 percent compared with a 1830 m. (6000 ft.) airplane. Penalties for mechanical flap and hybrid OTW/IBF are about equal from the standpoint of noise level and direct operating cost at twice 1972 fuel prices; the hybrid is superior in fuel consumption and its DOC would become superior with further increases in fuel price.

It is suggested that attention be given to restricting the 90 EPNdB contour to 1 sq. Km. (0.39 sq. mi.) in area and 2.3 Km. (7500 ft.) in length. Cost and fuel penalties increase for more stringent requirements. Shorter footprint lengths would require shorter field length requirements and would change the optimum design from four- to two-engines in the OTW/IBF aircraft.

8.2.3 Effect of Field Length

The effect of field length on direct operating costs and fuel consumption can be summarized for three potential noise requirements as follows (Reference is the 1830 m. (6000 ft.) aircraft meeting FAR 36-10):

NOISE REQUIREMENT	LIFT CONCEPT	NO. OF ENGINES	ENGINE FPR	FIELD LENGTH m. (FT.)	DOC-2 PENALTY PCTG	FUEL PENALTY PCTG
REFERENCE	MF	2	1.35	1830 (6000)	0	0
FAR 36 - 10 OR 15	MF*	2	1.35	910 (3000)	15	27
FAR 36 - 15	OTW/IBF	4 (SPLITTER)	1.35	910 (3000)	17	14
95 EPNdB @ 152 m. (500 FT.)	OTW/IBF	4	1.35	910 (3000)	15	6
90 EPNdB AREA						
2.6 SQ. Km (1 SQ.MI.)	MF*	2	1.40	910 (3000)	14	27
1.3 SQ. Km (0.5 SQ.MI.)	OTW/IBF	4	1.37	910 (3000)	15	6
0.83 SQ. Km (0.32 SQ.MI.)	OTW/IBF	4 (SPLITTER)	1.35	910 (3000)	17	14
90 EPNdB LENGTH						
2.3 Km (7500 FT.)	OTW/IBF	4 (SPLITTER)	1.35	910 (3000)	17	14
1.86 Km (1 N.MI.)	OTW/IBF	2	1.35	850 (2800)	20	50
1.22 Km (4000 FT.)	OTW/IBF	2	1.25	610 (2000)	40	60

* MF AT LOW WING LOADING REQUIRES RIDE QUALITY GUST ALLEVIATION AND DEMONSTRATION FOR PASSENGER ACCEPTABILITY ON LONGER STAGE LENGTHS.

TABLE XLVIII: DOC AND FUEL PENALTIES @ FIELD LENGTH 910 m. (3000 FT.) OR LESS -- M 0.75

Field Length		% Penalties for Meeting					
		FAR 36-15		1 sq. Km 90 EPNdB		90 EPNdB 2.3 Km	
Meters	Feet	DOC	Fuel	DOC	Fuel	DOC	Fuel
1830	6000	3	4	10	10	17	14
1220	4000	3	4	10	10	17	14
915	3000	17	14	16	10	17	14

To meet FAR 36 minus 15, the landing field length must be reduced below 1830m (6000 ft.) because of approach noise. If the requirement is 1 sq. Km for the 90 EPNdB foot print, the penalty is 10 percent in DOC and fuel and and additional penalty is incurred for reduction in field length to 1220m. If the length of the 90 EPNdB foot print is required to be 2.3 Km, the 910m (3000 ft.) field length is required and the DOC and fuel penalties are 17% and 14%, respectively.

8.2.4 Other Lift Concepts

Table XLIX summarizes the characteristics of aircraft designed for 610m and 910m field lengths. As noted previously, the AW and EBF aircraft represented here have about the same noise characteristics as the OTW/IBF aircraft with 1.35 FPR engines. Their direct operating costs are 10 to 11 percent higher. Penalties for meeting noise requirements would be increased to approximately double those listed in sections 8.2.2 and 8.2.3.

The deflected slipstream aircraft sized to match the available T-56 turboprop engine represent a very interesting short haul approach for missions in which M 0.55 cruise and relatively low wing loading are acceptable to the passenger market. They have not been entered into the comparisons because of the considerations noted in the introduction to this section and discussed further in Section 10.

8.2.5 Engine Characteristics

Selection of engine characteristics will be considered from the standpoint of fan pressure

FIELD LENGTH	610 M (2000 FT)				910 M (3000 FT)			
CONCEPT	NO. OF ENG. (FPR)	M	FUEL KG (LB)	DOC-2 ¢/ASSM	NO. OF ENG. (FPR)	M	FUEL KG (LB)	DOC-2 ¢/ASSM
OTW/IBF	4 (1.35)	0.75	4,944 (10,900)	1.961	4 (1.35)	0.75	4,400 (9,700)	1.831
	—	—	—	—	4 (1.47)	0.75	5,117 (11,280)	1.820
MF	—	—	—	—	2 (1.35)	0.70	5,089 (11,220)	1.818
AW	—	—	—	—	2 + 2 (1.35/3.0)	0.75	5,688 (12,540)	2.015
EBF	4	0.65	5,003 (11,030)	2.196	4 (1.25)	0.65	4,427 (9,760)	2.046
DEFLECTED SLIPSTREAM	—	—	—	—	4 (T-56)	0.55	3,293 (7,260)	1.629

TABLE XLIX: SUMMARY OF 610 M AND 910 M (2000 AND 3000 FT) AIRCRAFT (MIN. DOC 2) ratio effect on fuel as well as noise, and, qualitatively, the effects of gearing the fan, fan stages, and variable pitch.

The uninstalled specific fuel consumption of the three point design engines is plotted on Figure 288 at their respective fan pressure ratios. Also shown is the installed SFC based on pylon thrust at M 0.8 and 9140m (30,000 ft.) altitude. The TF39 and some other existing engines are also shown, along with a trend line which is considered to represent the basic relation of SFC to FPR. If the trend lines are representative, the point design engines at 1.25 and 1.47 have caused an over-estimation of fuel consumption (and direct operating cost) in the aircraft analyses, as far as representation of the basic effect of fan pressure ratio is concerned. The weights of these engines do not compensate for this over-estimation. Figure 289 shows the same installed SFC data for M 0.8 and also adds trend lines for M 0.75 and M 0.55. The trend lines, if verified, would indicate that aircraft fuel consumption and DOC would be less sensitive to FPR than the results using the three point design engines have indicated. It was shown earlier that engine thrust to engine weight was not an over-riding factor in fuel or DOC. (For a 1220m (4000 ft.) MF airplane an 8 percent change in engine weight had the same effect on fuel consumption as a one percent change in SFC; a 5 percent change in engine weight had the same effect on DOC-2 as a one percent change in SFC.) Engine weight trend lines would also be associated with a basic relationship to FPR and would be different for specific engine features such as fan gearing and stages and variable pitch mechanics.

From the foregoing, it is concluded that in-depth analyses are needed of aircraft and engines which are designed for fuel economy and for noise characteristics which differ from those in the QCSEE program. For example, engines could be designed, at a given noise level, for optimizing the lapse rate to fit airplane requirements for minimum fuel consumption and desired field length such as M 0.75 at 9140m (30,000 ft.) and 910m (3000 ft.) field length (in the current study, the airplanes were optimized to fit the engines, including their lapse rates). The engine designs in the QCSEE program were biased towards minimum exhaust velocity because of the emphasis on flap interaction noise in the under-wing EBF concept. Thus, engines have not been optimized for the

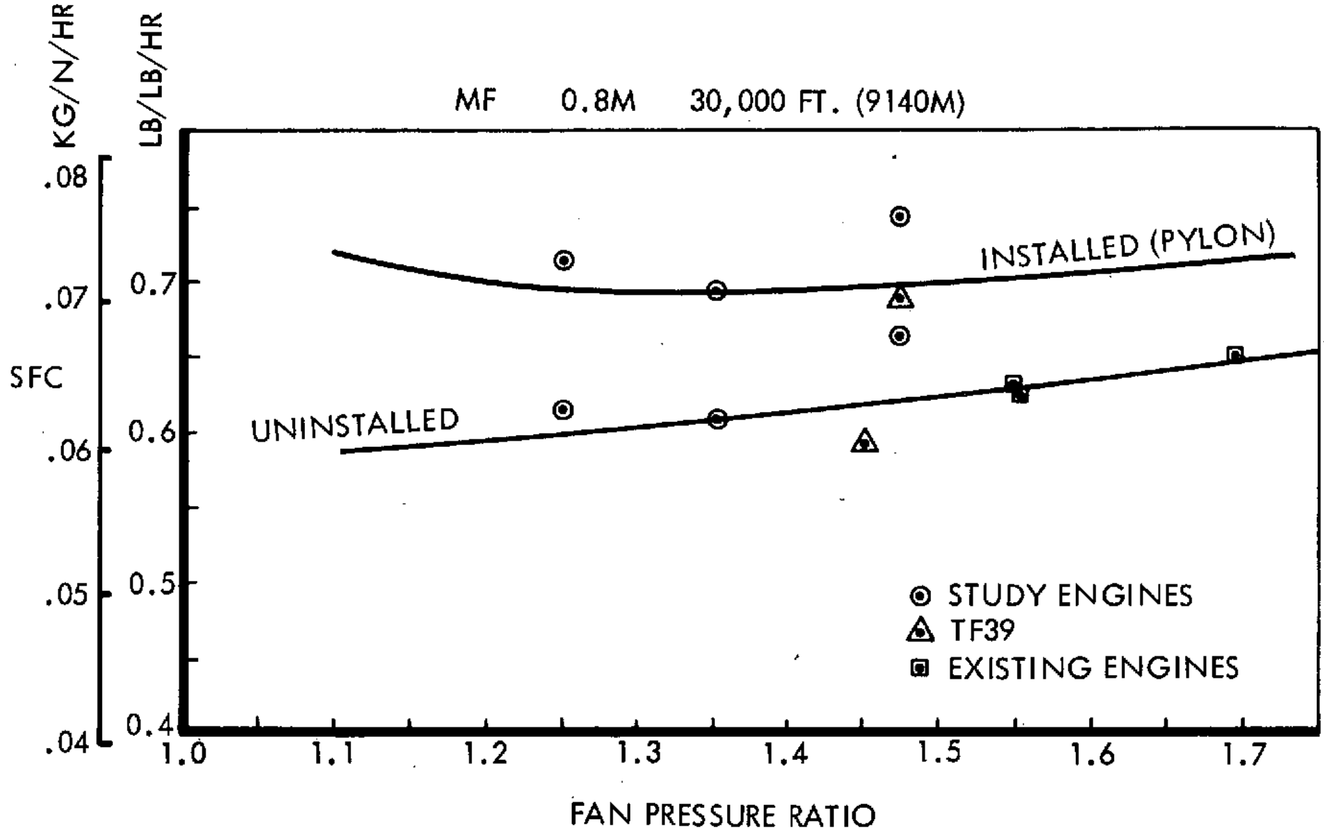


FIGURE 288 EFFECTS OF INSTALLATION ON SFC

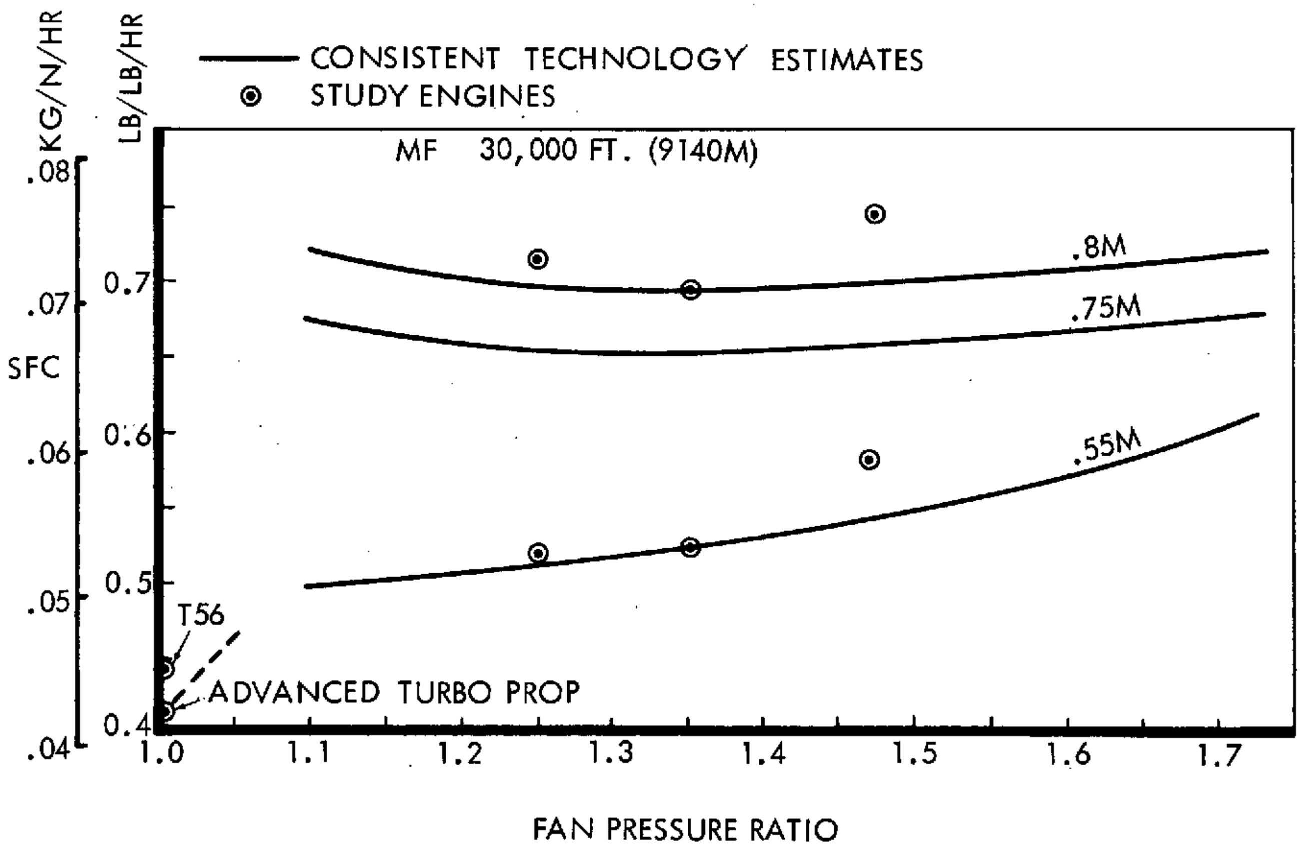


FIGURE 289 SFC (PYLON THRUST) VS FPR

conditions of minimum fuel consumption and acceptably low noise in the currently favored concepts of hybrid OTW/IBF and mechanical flap aircraft. A closely integrated aircraft/engine design study is strongly recommended. The results of the design studies in the pre-hardware phases of the QCSEE program should now be extended to cover the current conditions, closely integrated with the airplane designs.

It is further concluded that the best engine characteristics will be most dependent on noise requirements -- different from those imposed in the pre-hardware phases of the QCSEE program. The data described previously showed marked superiority in aircraft fuel consumption and direct operating cost at favorable noise levels for the FPR 1.35 engine with a geared stage-and-a-half fan. The indications are that an upper limit of 1.35 to 1.4 would be imposed by the noise levels which have been recommended for serious consideration. Breakdown of noise sources into components indicate that exhaust noise and suppressible fan noise both require a limit of this sort. The question of gearing the fan, compared with direct drive, will remain uncertain at these fan pressure levels especially until maintenance uncertainties are pinned down. Use of a 1-1/2 stage fan appears beneficial, but has not been thoroughly evaluated. Tradeoff shows the cost of a variable pitch fan is not warranted in the current over-the-wing nacelle design. However, different mountings and nacelle configurations might alter this tradeoff; in a mechanical flap under-wing installation the variable pitch feature and conventional thrust reverser are close to a standoff.

In summary, the current data indicate that a fixed-pitch geared 1-1/2 stage fan engine with FPR of 1.35 is close to optimum from the standpoint of noise and fuel consumption at acceptable cruise speeds for short and long haul air transportation. A definitive aircraft/engine analysis is recommended to define firmly the commonality of short and long haul requirements and to establish in more detail the engine characteristics.

9.0 AIRLINE ECONOMICS

Sections 3.1 and 3.2 of Reference 2 presented the results of airline simulations and calculation of return on investment for the promising lift concepts of that study. Those results have been updated and extended for the promising aircraft defined in the current work.

9.1 STOL AIRCRAFT COSTS (DOC/IOC/ROI)

No Credit For Increased Range - The STOL aircraft characteristics and costs are shown in Tables L, LI, and LII for two hybrid aircraft and a mechanical flap aircraft. The costs in Tables L, LI and LII are based on the simulated Eastern Air Lines (EAL) system for the 1985 time period where the system is comprised of the R/STOL aircraft, the CTOL Twin, and the B727-200. These costs are also determined for the 1990 time period and these costs for the two time periods provide the system inputs for the cash flow analysis leading to the calculation of ROI by the CAB method and the discounted cash flow method. The average stage length for the STOL aircraft in Reference 2 was 410 km. to 450 km. (220 to 245 nautical miles) whereas the aircraft was designed for 930 km. (500 n.mi.). The follow-on aircraft are also designed for 930 km. (500 n.mi.) with R/STOL takeoff and with the capability of carrying full load to 2800 km. (500 n.mi.) with CTOL takeoff. The ROI and DOC shown in Tables L, LI, and LII represent the extreme case where the extended range is not utilized; utilization remains at 7 hr/day. Figure 290 shows the DOC versus range for three R/STOL aircraft at a utilization of 7 hr/day (2555 hr/year). These DOC's may be compared to the DOC's for the Twin CTOL and the 727-200 CTOL at 3285 hr/yr utilization as shown in Figures 291 and 292. The number of seats used in calculating the DOC's as shown in Figures 290, 291 and 292 is 148 for the STOL aircraft, 205 for the Twin and 148 for the 727-200. The breakdown of the DOC for the three R/STOL aircraft is provided in Table LIII.

Effect of 1500 N.Mi. Design Range - The previous short haul system parameters, such as utilization and average stage length, were based on route assignments for the R/STOL aircraft under 930 km. (500 nautical miles) because that was its design requirement. The

3000 FT, FPR 1.35, MACH 0.8, 30000 FT CRUISE ALT, HYBRID

AIRCRAFT CHARACTERISTICS

WEIGHTS		PERFORMANCE		COSTS	
GROSS	170529	NO. OF ENGINES	2	FLYAWAY	8881600
OWE	102039	TOTAL TAXI TIME	0.084	AIRFRAME	6762514
WA	84475	THRUST/ENGINE	39923	ENGINE	2119086

NO. OF PASSENGERS 148 PASS. WT. 165 BAGGAGE/PASS 35

DIRECT OPERATING COST FACTORS

BASED ON 1972 DOLLARS		ESCALATION	1.260		
INSURANCE RATE	0.012	NO. OF CREW	3	FUEL COST	0.0197
DEPRECIATION TERM	12	RESIDUAL VALUE	0.100	LABOR RATE	6.00
		AIFRAME SPARES	0.100	ENGINE SPARES	0.250
MAINTENANCE BURDEN	1.3	AIRFRAME MAINT.	0.675	ENGINE MAINT.	0.750

INDIRECT OPERATING COST FACTORS

SYSTEM EXPENSE	0.4100	LOCAL EXPENSE	1.4300
AIRCRAFT CONTROL	16.530	FOOD AND BEVERAGE	0.2000
NO. OF HOSTESS	4	HOSTESS EXPENSE	20.000
PASSENGER SERVICE	3.650	OTHER PASS. EXP.	0.0044
CARGO HANDLING	70.43	OTHER CARGO EXP.	0.0086
GENERAL AND ADMIN	0.06		

SYSTEM CHARACTERISTICS

FLEET SIZE	33.58	UTIL. HR/DAY	7.00	FLTS/DAY	297.98
LOAD FACTOR	46.86	PAX/YEAR	7543090	RPM/YR	2222193232
BASIC REVENUE	12.00	REVENUE/RPM	0.0628	FARE DISCOUNT	0.85

SYSTEM RESULTS

RANGE S MI.	115	230	345	460	575	254
BLOCK TIME	0.476	0.670	0.863	1.084	1.284	0.710
BLOCK FUEL	6756	8988	11189	13165	15080	9450
DOC $M	64.31	82.77	101.21	121.05	139.29	86.62
IOC $M	89.99	93.06	96.13	99.56	102.67	93.70
COST $M	154.30	175.83	197.34	220.61	241.96	180.32
REVENUE $M	130.65	184.35	238.06	291.76	345.47	195.56
EARNINGS $M	-12.30	4.43	21.17	37.00	53.82	7.92
AFT TAX ROI						2.34
DOC ¢/ASSM	3.474	2.236	1.822	1.635	1.505	2.119
IOC ¢/ASSM	4.861	2.513	1.731	1.344	1.109	2.292
COST ¢/ASSM	8.335	4.749	3.553	2.979	2.614	4.410

TABLE L: AIRPLANE CHARACTERISTICS AND COSTS - OTW/IBF 910M (3000 FT.) F.L. COMPUTER PRINT-OUT

2000 FT,FPR 1.35,MACH 0.8,30000 FT CRUISE ALT, HYBRID

AIRCRAFT CHARACTERISTICS

WEIGHTS		PERFORMANCE		COSTS	
GROSS	162725	NO. OF ENGINES	4	FLYAWAY	9659251
OWE	98286	TOTAL TAXI TIME	0.084	AIRFRAME	6506178
WA	82947	THRUST/ENGINE	17148	ENGINE	3153073

NO. OF PASSENGERS 148 PASS. WT. 165 BAGGAGE/PASS 35

DIRECT OPERATING COST FACTORS

BASED ON 1972 DOLLARS		ESCALATION	1.260		
INSURANCE RATE	0.012	NO. OF CREW	3	FUEL COST	0.0197
DEPRECIATION TERM	12	RESIDUAL VALUE	0.100	LABOR RATE	6.00
		AIFRAME SPARES	0.100	ENGINE SPARES	0.250
MAINTENANCE BURDEN	1.3	AIRFRAME MAINT.	0.675	ENGINE MAINT.	0.750

INDIRECT OPERATING COST FACTORS

SYSTEM EXPENSE	0.4100	LOCAL EXPENSE	1.4300
AIRCRAFT CONTROL	16.530	FOOD AND BEVERAGE	0.2000
NO. OF HOSTESS	4	HOSTESS EXPENSE	20.000
PASSENGER SERVICE	3.650	OTHER PASS. EXP.	0.0044
CARGO HANDLING	70.43	OTHER CARGO EXP.	0.0086
GENERAL AND ADMIN	0.06		

SYSTEM CHARACTERISTICS

FLEET SIZE	34.32	UTIL. HR/DAY	7.00	FLTS/DAY	297.98
LOAD FACTOR	46.86	PAX/YEAR	7543090	RPM/YR	2222193232
BASIC REVENUE	12.00	REVENUE/RPM	0.0628	FARE DISCOUNT	0.65

SYSTEM RESULTS

RANGE S MI.	115	230	345	460	575	254
BLOCK TIME	0.486	0.684	0.883	1.109	1.314	0.720
BLOCK FUEL	6104	8121	10110	11895	13620	8539
DOC $M	68.29	87.92	107.54	128.84	148.36	92.01
IOC $M	89.04	92.22	95.40	98.97	102.21	92.89
COST $M	157.33	180.14	202.94	227.81	250.57	184.90
REVENUE $M	130.65	184.35	238.06	291.76	345.47	195.56
EARNINGS $M	-13.87	2.19	18.26	33.26	49.35	5.54
AFT TAX ROI						1.46
DOC ¢/ASSM	3.689	2.375	1.936	1.740	1.603	2.250
IOC ¢/ASSM	4.810	2.491	1.718	1.337	1.104	2.272
COST ¢/ASSM	8.499	4.866	3.654	3.077	2.707	4.522

TABLE LI: AIRPLANE CHARACTERISTICS AND COSTS - OTW/IBF 610M (2000 FT.) F.L. COMPUTER PRINT OUT

4000 FT, FPR 1.35, MACH 0.8, 30000 FT CRUISE ALT, MF

AIRCRAFT CHARACTERISTICS

WEIGHTS		PERFORMANCE		COSTS	
GROSS	145011	NO. OF ENGINES	2	FLYAWAY	7628676
OWE	84954	TOTAL TAXI TIME	0.084	AIRFRAME	5786065
WA	71005	THRUST/ENGINE	26777	ENGINE	1842611

NO. OF PASSENGERS 148 PASS. WT. 165 BAGGAGE/PASS 35

DIRECT OPERATING COST FACTORS

BASED ON 1972 DOLLARS		ESCALATION	1.260		
INSURANCE RATE	0.012	NO. OF CREW	3	FUEL COST	0.0197
DEPRECIATION TERM	12	RESIDUAL VALUE	0.100	LABOR RATE	6.00
		AIFRAME SPARES	0.100	ENGINE SPARES	0.250
MAINTENANCE BURDEN	1.3	AIRFRAME MAINT.	0.675	ENGINE MAINT.	0.750

INDIRECT OPERATING COST FACTORS

SYSTEM EXPENSE	0.4100	LOCAL EXPENSE	1.4300
AIRCRAFT CONTROL	16.530	FOOD AND BEVERAGE	0.2000
NO. OF HOSTESS	4	HOSTESS EXPENSE	20.000
PASSENGER SERVICE	3.650	OTHER PASS. EXP.	0.0044
CARGO HANDLING	70.43	OTHER CARGO EXP.	0.0080
GENERAL AND ADMIN	0.06		

SYSTEM CHARACTERISTICS

FLEET SIZE	35.80	UTIL. HR/DAY	7.00	FLTS/DAY	297.98
LOAD FACTOR	46.80	PAX/YEAR	7543090	RPM/YR	2222193232
BASIC REVENUE	12.00	REVENUE/RPM	0.0628	FARE DISCOUNT	0.85

SYSTEM RESULTS

RANGE S MI.	115	230	345	460	575	254
BLOCK TIME	0.506	0.714	0.922	1.159	1.374	0.757
BLOCK FUEL	5389	7169	8926	10501	12029	7538
DOC $M	57.11	74.05	90.98	109.34	126.18	77.59
IOC $M	85.36	88.49	91.64	95.16	98.36	89.15
COST $M	142.47	162.55	182.62	204.50	224.54	166.74
REVENUE $M	136.65	184.35	236.06	291.76	345.47	195.56
EARNINGS $M	-6.15	11.34	28.85	45.38	62.89	14.99
AFT TAX ROI						4.83
DOC ¢/ASSM	3.085	2.000	1.638	1.477	1.363	1.898
IOC ¢/ASSM	4.611	2.390	1.650	1.285	1.063	2.180
COST ¢/ASSM	7.696	4.390	3.288	2.762	2.426	4.078

TABLE LII AIRPLANE CHARACTERISTICS AND COSTS – MF 1220M (4000 FT.) F.L. COMPUTER PRINT-OUT

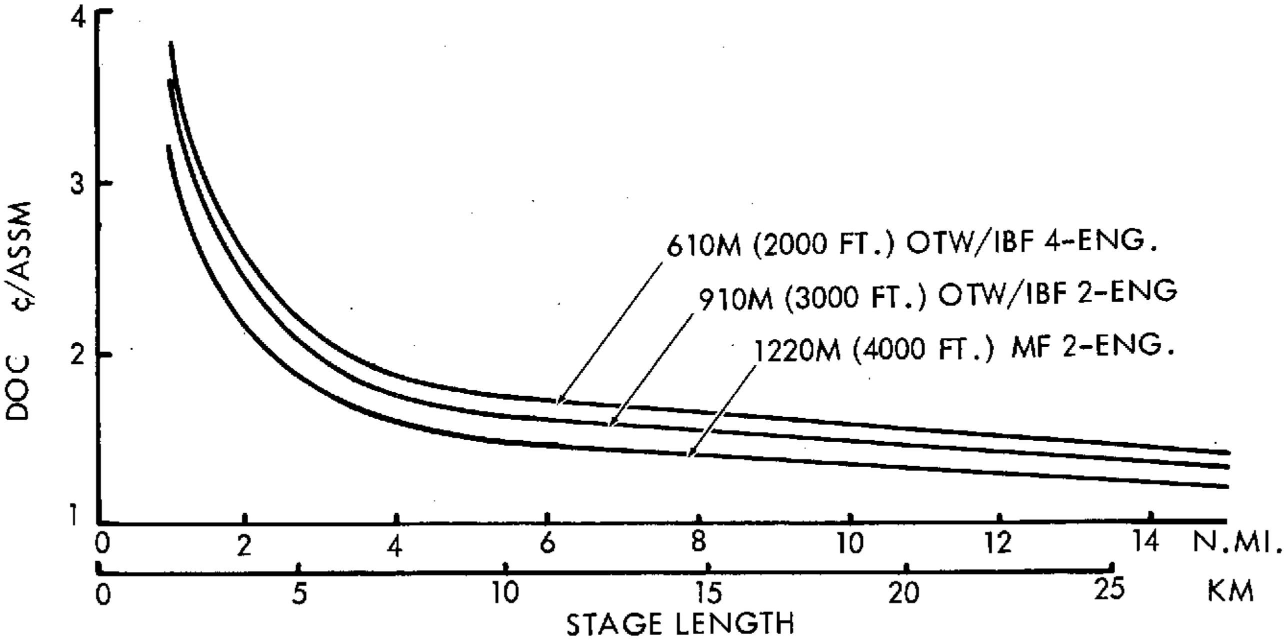


FIGURE 290 DOC VERSUS RANGE - STOL AIRCRAFT @ 2555 HOURS UTILIZATION

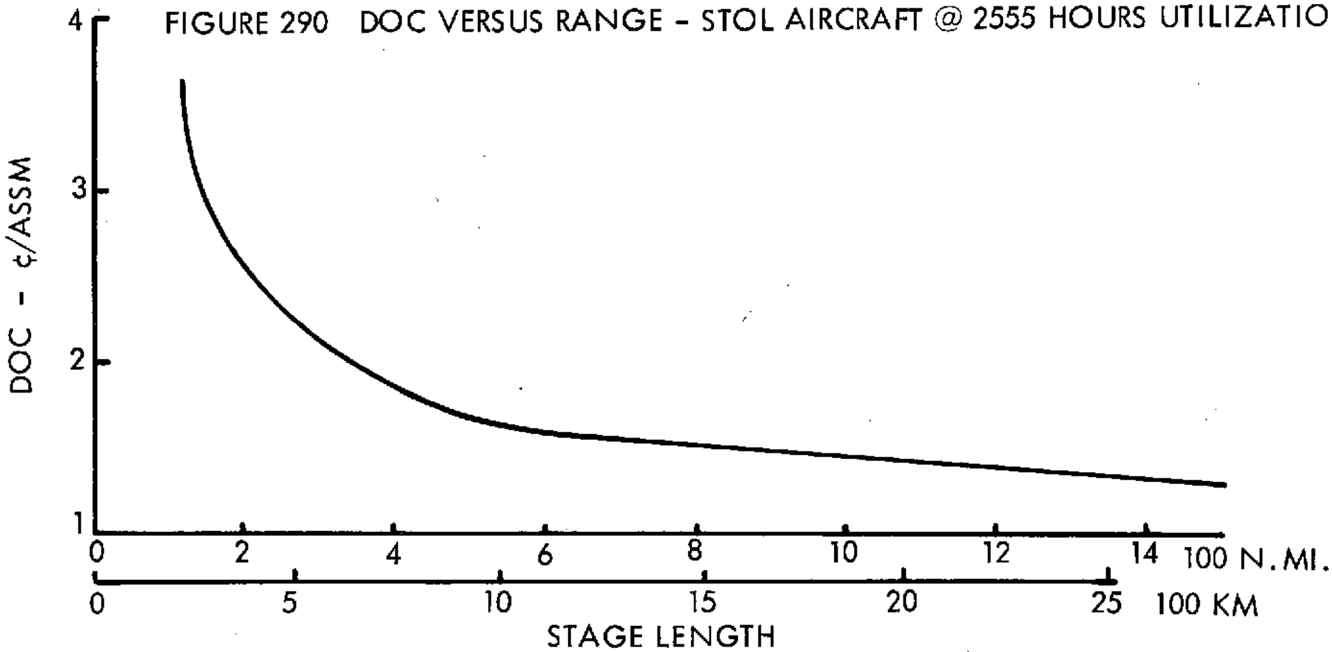


FIGURE 291 DOC VS RANGE (TWIN CTOL) @ 3285 HOURS UTILIZATION

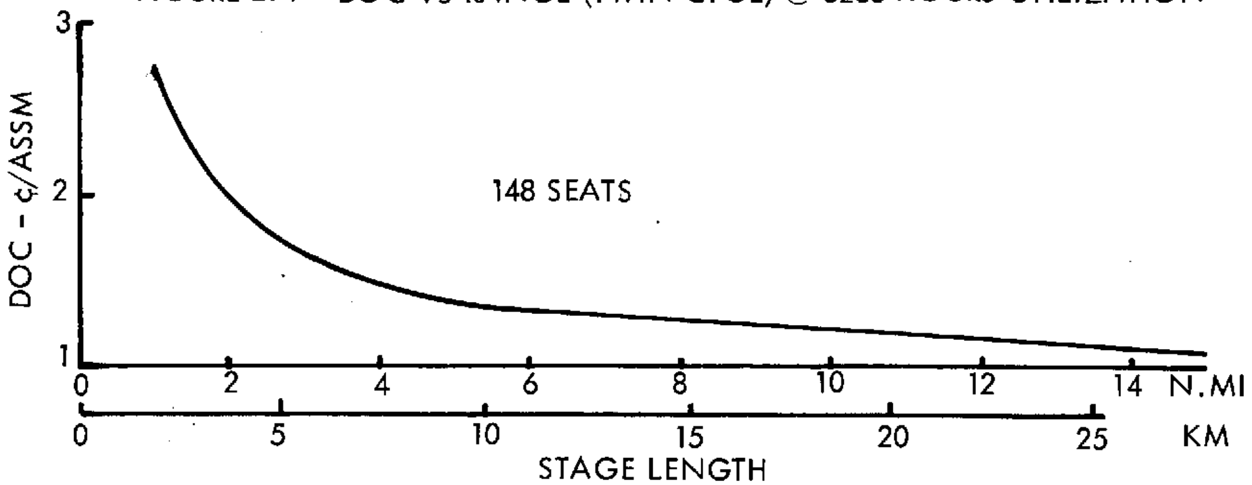


FIGURE 292 DOC VERSUS RANGE - 727-200 @ 3285 HOURS UTILIZATION

TABLE LIII

DOC BREAKDOWN - STOL AIRCRAFT

DOC at 930 km. 500 N. Mi.)	910m. (3000') Hybrid 2 Engine	610m. (2000') Hybrid 4 Engine	1220m. (4000') MF 2 Engine
Crew	.403	.413	.432
Fuel *	.528	.477	.421
Insurance	.093	.104	.086
Depreciation	.661	.744	.608
Maintenance	.541	.635	.478
DOC $/St. Mi.	2.227	2.373	2.024
DOC ¢/ASSM	1.505	1.603	1.368
DOC ¢/ASSM	1.732	1.845	1.575

* Fuel cost at $0.0197/lb. = 13¢/gal.

Utilization 7 hr./day

R/STOL aircraft designed by the criteria used for the current study are designed to operate at 2800 km. (1500 N.Mi.) range with no reduction in payload. The added range capability to these aircraft could mean assignment to longer stage lengths and thus an increase in the utilization and a decrease in the DOC, which in turn increases the ROI substantially. If the utilization for the 2-engine hybrid is raised to 3285 hours per year by taking advantage of its longer range capability, the DOC is reduced by 8.1% and its cost is then comparable to the 727-200 with 148 seats at a 10 minute delay. The DOC's for the 4-engine hybrid and the 2-engine mechanical flap airplanes are also reduced by 8% by increasing the utilization from 2555 hours to 3285 hours per year. Variation of DOC with utilization and fuel cost is shown in Figure 293. DOC at 3285 hours utilization is shown as a function of stage length in Figure 294.

9.2 RETURN ON INVESTMENT (ROI)

The R/STOL aircraft with 2800 km. (1500 N. Mi.) range capability were introduced in the simulated EAL short haul system. The cost output in terms of DOC/IOC and ROI was based on the following premises:

- Fuel cost doubled
- Fare increased by 12%
- Utilization increased and commensurate with increased range - i.e. 410 km. to 560 km. (254 st. miles to 345 st. miles)
- $\text{ROI} = \dfrac{\text{Annual Income after Taxes + Interest}}{\text{Average Investment}}$

The method for determining ROI conforms to the CAB method and takes into account the aircraft delivery schedule, the operating expense, revenue, the debt to equity ratio, the interest rate for borrowed money, and the average book value of the investment. The average stage length is increased from the 410 km. (254 st. miles) obtained from the original simulation to 560 km. (345 st. miles) for the STOL aircraft. The utilization is also increased from the 2555 hours to 2650 hours.

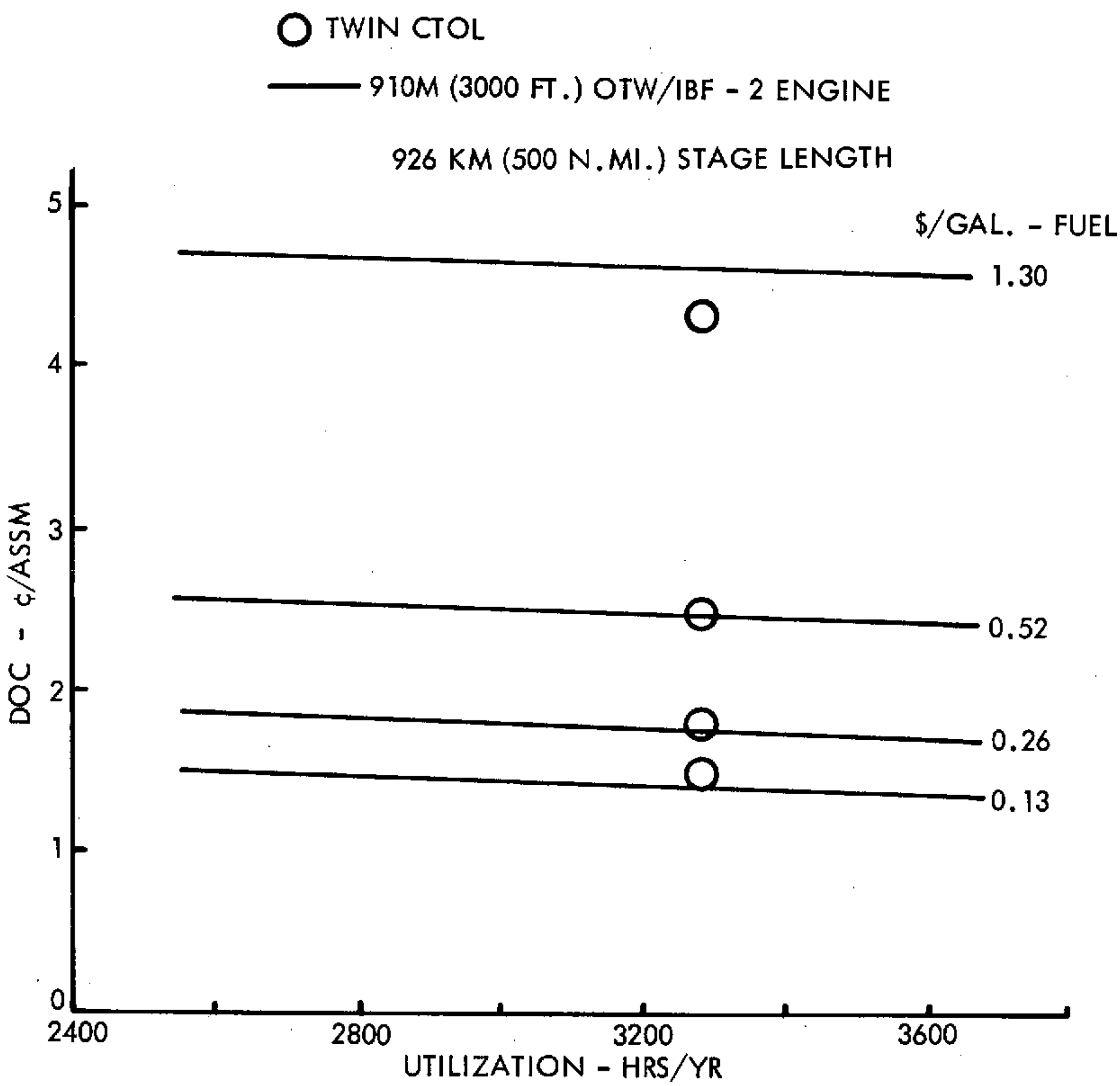


FIGURE 293 DOC VERSUS UTILIZATION AND FUEL PRICE

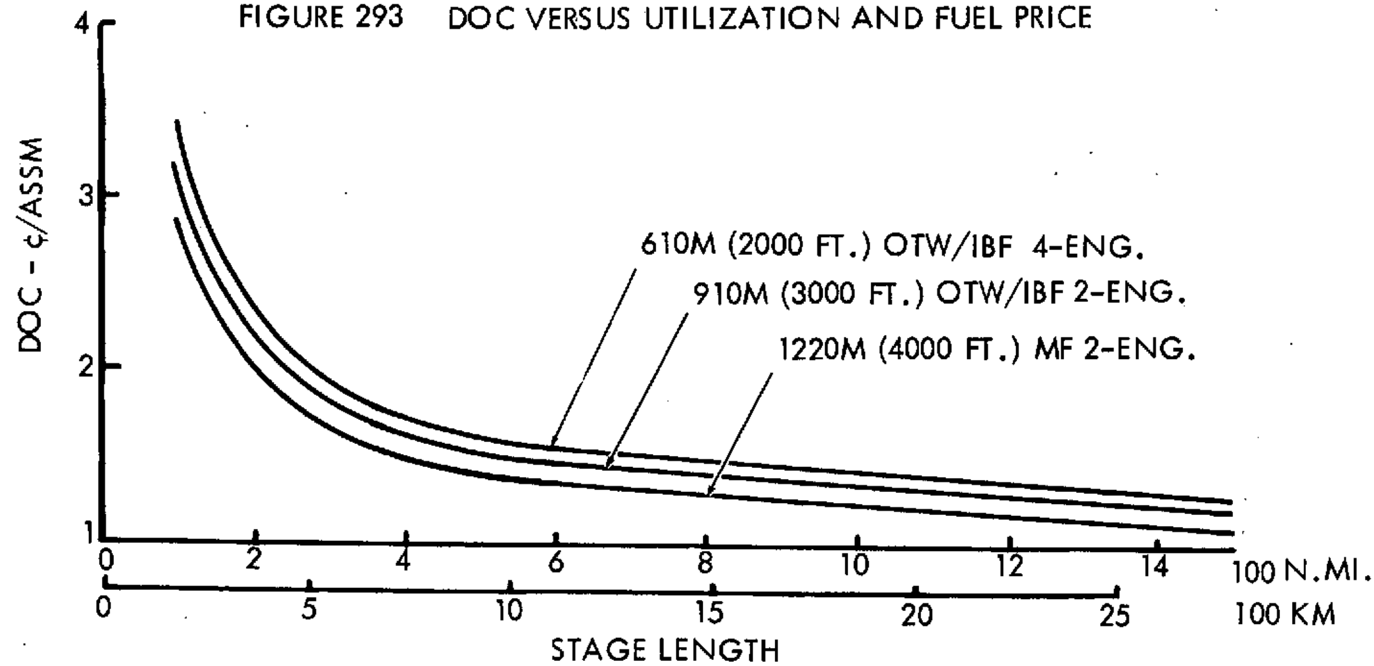


FIGURE 294 DOC VERSUS RANGE - R/STOL AIRCRAFT @ 3285 HOURS UTILIZATION

The load factor for the STOL aircraft was 46 percent as derived from the EAL short haul simulation where the average stage length for the STOL is 410 km. (220 nautical miles). Taking advantage of the added range capability of the STOL aircraft would improve its economics. An indication of the results of assigning the STOL to longer stage lengths is shown in Figure 295 which shows the relationship between the DOC and the ROI for two cases. The first case assumes the same DOC factors as were used in Reference 2. The other case reflects increases in fuel and fare costs as assumed in this study. The fuel cost is doubled and the fare is increased 12 percent above those used in Reference 2.

Points A and A' are determined from the system parameters as determined from the EAL simulation where the utilization was 2555 hours and the average stage length was 410 km. (220 N. Mi.). Points B and B' are established by increasing the stage length to 560 km. (300 N. Mi.) and the utilization to 2650 hours per year. Points C and C' are determined by increasing the average stage length to 930 km. (500 N. Mi.) and the utilization to 2900 hours. The ROI's as calculated for these additional ranges are for the baseline R/STOL aircraft [910m. (3000') Hybrid] and for an average of 5 years of operation.

Doubling the fuel cost to 25.6 cents per gallon does not alter the ROI appreciably with a 12 percent increase in fare which offsets the increase in fuel cost. At the short stage length the fuel cost slightly overrides the fare increase but at longer ranges the fare slightly over compensates the fuel cost increase. This is due to the higher SFC's at the short range because of the higher percentage of total flight time spent in climb. For instance, the block fuel per block hour consumption is approximately 6350 Kg (14,000 pounds) per hour for the 910m. (3000') hybrid at 370 Km (200 nautical miles) range but approximately 5440 Kg (12,000 pounds) per hour at 926 km (500 nautical miles) range.

The same general relationship of ROI to DOC as shown in Figure 295 has been observed in other comparisons. At a given fare level and load factor the DOC must be less than

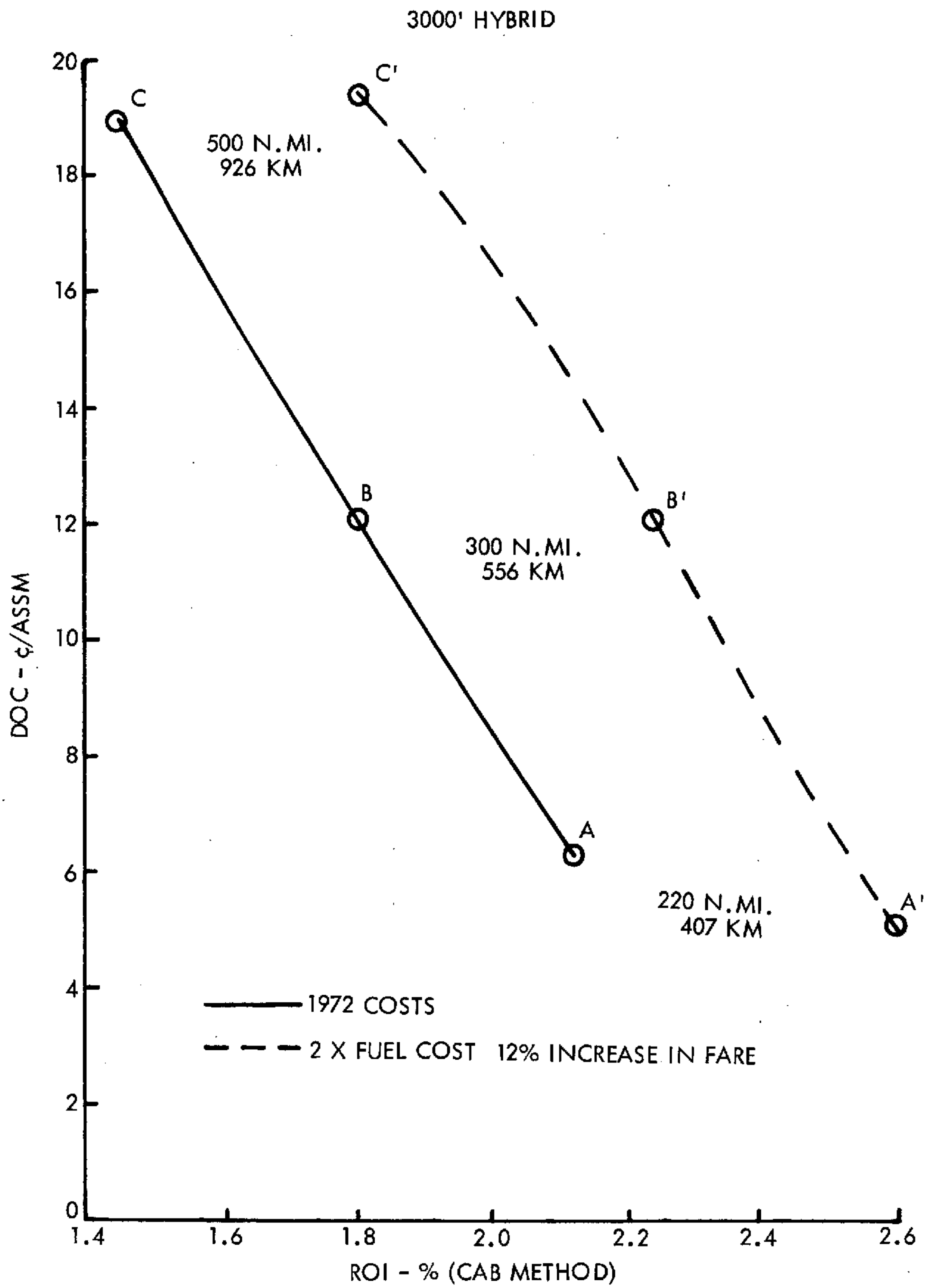


FIGURE 295 DOC VERSUS ROI (R/STOL AIRCRAFT) AT 3285 HOURS UTILIZATION

some critical value for a positive ROI. If the DOC is lowered, the ROI rises predictably. The fare basis used was the CAB Phase 9 recommendation. Fare realization was taken at 85 percent of this fare due to fare discounting. For the cases of increased fuel cost, the net fare was raised 12 percent to approximate the changes that have occurred recently; this partially takes into account the new fare structure established recently by the CAB in which short-haul fares were raised.

10.0 COMPROMISE SOLUTIONS

10.1 COMPATIBILITY OF SELECTION CRITERIA

Previous sections have shown that noise criteria, field performance, and fuel price all have a strong effect on economics. Compromise solutions for the high-density short-haul air transportation system will be examined for combinations of these factors, with some reference to the long haul and low-density short haul scenarios.

It is proposed that a valid simplification can be made by establishing the assumption that fuel prices will be stabilized at two to four times 1972 levels, and that equitable return on investment will be possible by adjustment of fare levels; it appears that such fare adjustments would not be so radical as to alter the passenger preference for air travel. In Section 9, it was shown that a 12 percent fare increase approximately compensated for a doubling of fuel cost.

10.1.1 Commonality of Engine Requirements with Long-Haul

Commonality of the engine with long-haul applications is a significant factor in short-haul economics. Therefore, the potential environment and characteristics of advanced long-haul aircraft should be evaluated. At the projected fuel prices it is suggested that long-haul aircraft may be designed for cruise speeds at or below M 0.8 for best economy. Such an aircraft might have to compete with a M 0.86 airplane for passengers; in the past, higher speeds have been considered a prime attraction. Airline decision on specifying new long-haul equipment might be based on a direct operating cost differential in which M 0.8 aircraft were five to ten percent lower than M 0.86 aircraft. At 50 percent load factor, this differential would represent a cost per passenger of \$2 to \$4 on a 2000 N.Mi. trip and a penalty in block time of about 18 minutes (out of 4 hours). It is difficult to predict whether the passenger would select the slower airplane if there were freedom to set competitive fares with a differential of this amount -- only one to two percent of the total fare.

It is recognized that analyses of the effect of fuel shortages and higher fuel prices on long haul are underway under NASA sponsorship. These could have significant impact on the conclusions reached for short-haul economics and engine selection. It is concluded from the above cursory analysis that the choice of engine -- bypass ratio and fan pressure ratio -- on the basis of lower cruise speeds for long-haul aircraft is not definitive from the standpoint of economics and fuel consumption alone. If fuel prices more than triple or if fuel allotments force a higher importance to fuel conservation it is much more likely that design speeds would be lowered and that fan pressure ratios of the order of 1.35 would be selected for advanced long-haul and short-haul airplanes.

Noise criteria for long-haul aircraft should also be examined for long-haul aircraft in considering the engine commonality aspect. It is estimated that current intermediate bypass engines can be used with advanced aircraft to satisfy a FAR 36 minus 10 dB requirement although design approach speeds may need to be lowered slightly to satisfy approach noise. (Lowering approach speed decreases the aerodynamic source noise and permits a higher glide path, if Microwave Landing System equipment is available, while still maintaining the same acceptable rate of descent; approach noise is decreased because less power is carried on the engines and the height of the airplane is increased over the measuring point.) Probably only small decreases in approach speed would be necessary although these would require slightly larger wings and some increase in cost.

If FAR 36 minus 15 dB were imposed (intermediate in the CARD study 1981 research goal, Ref. 11) the principal penalty would be the further reduction in approach speed toward the equivalent of a 4000-foot airplane. (This appears to be a quantifiable solution; other means of reducing approach noise might be developed.) Engine fan pressure ratios of 1.35 to 1.40 would be required; this in turn would force cruise speed down but the associated fuel savings might well compensate for the penalty of the larger wing required for approach. Restriction of footprint areas for long-haul aircraft would tend to have the same effects as a FAR 36 minus 15 criteria. Definitive analyses of these aspects of long-haul systems are needed; they were, of course, outside the scope of the present study.

It is concluded that there is sufficient probability of application of 1.35 FPR (approximately) engines to long-haul aircraft that their costing and use in the short-haul analyses should be based on that premise.

10.1.2 Aircraft Design for 1220m. (4000 Ft.) Field Length

The mechanical flap aircraft using two 1.35 FPR engines is capable of meeting FAR 36 minus 15, with a DOC-2 penalty of 3 percent compared to the 1830 m. (6000 foot) airplane meeting FAR 36 minus 10. Its 90 EPNdB footprint is 1.36 sq. Km (0.526 sq.mi.) for takeoff and 0.243 sq. Km (0.094 sq.mi.) for landing. Takeoff footprint length is 2539 meters (8330 feet) and approach footprint length is 1448 meters (4750 feet). Design cruise speed is M 0.75 at 9140 meters (30,000 feet). Fuel consumption is 4 percent more than the 1830 m. (6000 foot) 2-engine airplane and 5 percent more than a 4-engine 1220 m. (4000-foot) airplane; DOC (2) of the 2-engine airplane is lower.

It is suggested that this airplane has excellent potential for application in many areas where the 1220 meter field length is appropriate. In many ways this conclusion coincides with the conclusions reached in planning the Europlane program. The airplane differs from the Europlane in using an advanced (rubberized) engine; in passenger size because of convenience in making comparison in the study and no restriction on engine size, and in placement of the engines on the wing (the Europlane engine placement was constrained by the forward fan noise dominance of the RB211 engines). If an engine of about 110 KN (25,000 lb.) thrust were developed, two, three, or four engine airplanes with passenger capacities of 150, 200, or 250 could be developed.

Aircraft with 1220 meters field length could partially relieve airport congestion by use of secondary airports and permit continued growth of airtransportation in the cases where additional runways of this length could be provided on hub airports. Noise criteria permitting a 90 EPNdB footprint, 1448 meters (4750 feet) long and 0.78 sq. Km. (0.3 sq.mi.) in area beyond each end of the runway would contribute no penalty in DOC or fuel. Conversely, the airplane described is the most economical airplane meeting those noise criteria. More stringent noise criteria would cause increasing cost penalties.

The airplane should also be of significant interest to airlines for operation from CTOL runways if credit for its low noise could be gained in a fleet noise improvement if an averaging criteria were established.

It is also concluded that the weight and cost penalty for a heavier fuel load to provide a longer range capability with CTOL takeoff would be more than counterbalanced by increased flexibility and utilization. Range with full payload should probably be increased to 1110 Km (600 N.Mi.) for R/STOL takeoff and 2780 Km (1500 N.Mi.) with CTOL takeoff.

Implementation of this aircraft requires primarily the propulsion development. A significant first step is obtaining answers to the questions of engine optimization, discussed in Section 8.2.5. A quiet clean R/STOL integrated airframe/engine study program is suggested. Following that study, and utilizing the technology from the QCSEE program, the development of an operational engine could be undertaken. The economic environment of the U.S. airline and aircraft industry would be the determining factor as to whether this development could be based on private enterprise risk funding.

The airframe technology is essentially in hand; wing with advanced airfoil and aspect ratio 10 for M 0.75 cruise do not require extensive new programs. Continuing of increasing high fuel prices is bringing closer the day when it will pay to replace aircraft having specific fuel consumption greater than 0.8. However, the engine development would be the pacing factor, placing the initial operation of the airplane described in the mid-1980's.

10.1.3 Aircraft Design for 910m. (3000 Ft.) Field Length

The hybrid OTW/IBF airplane using two 1.35 FPR engines is capable of providing 90 EPNdB contours less than 0.65 sq. Km (0.25 sq. mi.) and 1890 m. (6200 feet) beyond each end of the runway. A four-engine airplane with splitters in the inlet of the 1.35 FPR engines is also capable of meeting this requirement. Fuel consumption for the two-engine airplane designed for M 0.75 is 25 percent higher than for the 1830 m. (6000 ft.) MF airplane; for the four-engine hybrid, it is 8 percent higher. DOC-2 for either is 17 percent higher.

Mechanical flap aircraft with a low wing loading are capable of meeting these requirements at essentially the same DOC and fuel consumption as the two-engine hybrid; the four-engine hybrid is significantly superior in fuel consumption. The augmentor wing and externally blown flap aircraft are significantly higher in DOC. The deflected slipstream turboprop aircraft is superior in fuel consumption to all concepts and approximately equivalent in DOC if a new engine must be developed to match the desired aircraft size; as previously stated, it is recommended that it be removed from consideration for the high-density arena because of its low speed.

Thus, the configuration selection is not clear cut; since there is no demand currently for an implementation decision, it is suggested that several years are available in which additional data can be made available, such as the following:

- o Clarification of the land-side costs and needs for congestion relief associated with 610 m. to 1220 m. (2000 to 4000-ft.) short haul runways.

- o Demonstration of the gust alleviation technology and passenger acceptance of associated ride quality for an airplane with 293 Kg/m^2 (60 psf) wing loading.

- o Further development and demonstration of propulsive lift.

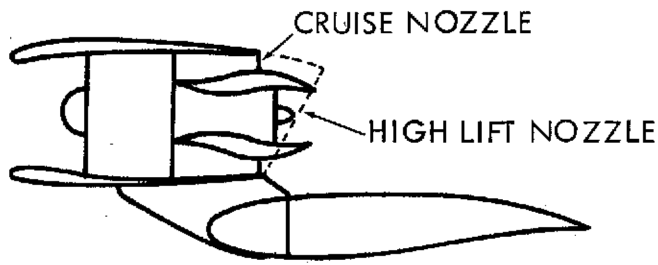
- o Establishment of rational specific noise criteria for long haul aircraft using existing runways and for short-haul aircraft using additional runways not now contributing to community noise.

- o Establishment of specific performance certification criteria (modification and implementation of a modified FAR Part XX).

On the latter point, the long duct nacelle used conservatively in the performance analyses, causes high losses in cruise. There is considerable potential for improvement in this area but experimental data are lacking. An improvement of 15 percent in DOC and ten percent in fuel consumption was estimated for an engine arrangement pylon-mounted above and forward of the wing, shown in Figure 296 (Reference 36).

- HIGH SPEED TESTS FROM VARIOUS SOURCES INDICATED THAT USB NACELLES INCURRED HIGH DRAG PENALTIES

- UNDER CONSIDERATION AT GELAC IS A PYLON MOUNTED USB NACELLE



  - TO MINIMIZE WING SCRUBBING AND INTERFERENCE EFFECTS
  - TO MINIMIZE NACELLE DRAG
  - TO REDUCE NACELLE WEIGHT TO THAT OF A MECHANICAL FLAP SYSTEM

- RECENT GELAC TESTS INDICATE THAT FILLET DESIGN AND HARD SURFACE JET EXHAUST REPRESENTATION CAN PRODUCE DRAG LEVELS COMPARABLE TO CONVENTIONAL UNDERWING MOUNTED NACELLES

FIGURE 296 POTENTIAL HIGH PERFORMANCE USB SYSTEM

Improvement less than this magnitude if verified experimentally, would make the OTW concept (possibly combined with IBF) an overwhelmingly superior approach at all field lengths up to 1830 m. (6000 feet).

It is concluded that the hybrid OTW/IBF concept with design cruise speed of M 0.75 and FPR 1.35 engines should be considered the best potential solution for 910 m. (3000-foot) field performance on the basis of lower fuel consumption and further potential for improvement. The versatility of full-load longer-range performance should be incorporated; using CTOL runways a 2780 Km (1500 n.mi.) range can be provided with a takeoff field length of 1280 m. (4200 feet). If 1.35 FPR engines with 57.8 KN (13,000 lb.) thrust were developed, aircraft sized for 90, 120, or 150 passengers could be designed with 2, 3 or 4 engines.

10.1.4 Aircraft Design for 610m. (2000 Ft.) Field Length

The choice of lift concept for this field length is clear cut; the four-engine hybrid OTW/IBF has a DOC-2 only 23 percent higher than the 1830 m. (6000 ft.) MF airplane and 7 percent higher than the 910 m. (3000 ft.) hybrid. (The MF cannot be considered below 914 m.) Previous estimates of the penalty of reduction in field length from 910 m. to 610 m. were 15 percent (Ref. 1) and 20 percent (Ref. 3). Whereas the former estimates represented a DOC penalty of 50 percent over CTOL, the current conservative optimization of the hybrid OTW/IBF indicates that 610 meter field performance may well be economically viable. These results would have significant consequences in conserving real estate.

No specific noise analyses were conducted for this airplane but is is estimated that footprint areas and lengths would be equivalent to those of the 914 meter aircraft and possibly smaller because of the inherently higher takeoff and approach gradients.

10.2 RECOMMENDED COMPROMISE CONCEPT

The potential of the OTW/IBF for 910 and 610m. (3000 and 2000 ft.) field lengths and small noise footprints indicates that it should be pursued in research and development programs. Implementation decisions are downstream so that confirmation of the results of current analyses can be obtained and a minimum risk program could be initiated in the 1980's. Decisions and actions which are appropriate are the following:

- Continuation of the Quiet STOL Research Airplane program.
- Implementation of further analytical and experimental development of improved nacelle and engine installations with emphasis on improving cruise performance and determining the optimum combination of high speed and low speed installation approach.
- Analytical refinement of engine design characteristics through an integrated airframe/engine study in the fan pressure ratio range of 1.3 to 1.4 for noise.
- Initiation of a quiet R/STOL engine development with technology drawn from the QCSEE program and guidance from the integrated airframe/engine study.

For the high-density arena, the aircraft should be designed with full-load capability for 2780 Km (1500 n.m.) range with CTOL takeoff, along with R/STOL capability for 930 KM (500 n.m.).

11.0 CONCLUSIONS AND RECOMMENDATIONS

Detailed conclusions and recommendations in a narrow context have been developed in many of the preceding sections of this report. Sections 8.0 and 10.0 have coalesced these and presented separate discussions of the major issues, i.e. fuel conservation, noise and compromise solutions. Section 11.1 summarizes the broader conclusions reached with respect to the STOL transport system; the STOL vehicle, its propulsion system, and STOL technology. Section 11.2 presents the contractor's principal recommendations arising from these conclusions.

11.1 CONCLUSIONS

Short Haul System

- The potential fuel savings which can be achieved by optimizing the vehicle configuration, mission speed and altitude far exceeds superficial expectations. Savings of the order of 25% (relative to minimum cost vehicles without energy conservation considerations) can be achieved. More surprisingly, comparable savings are attainable regardless of whether the field length is constrained to STOL distances or not, i.e. STOL vehicles can (proportionally) save as much fuel as RTOL or CTOL vehicles.

- Rising fuel prices are reflected in a substantial increase in the lowest attainable direct operating cost but because indirect operating costs do not change, it is likely that fares can be raised without radically perturbing passenger travel habits (e.g., a doubling of 1972 fuel prices could be accommodated in a 12% fare increase).

- The optimization of the R/STOL vehicle for elevated fuel prices entails a significant speed reduction of the order of 0.05 M for each doubling of fuel price. However, the minimum attainable DOC at high fuel prices is not very much less than that of a faster vehicle optimized for a lower fuel cost but using high-priced fuel; the competitive disadvantages which result from optimistic fuel predictions may be less serious than those resulting from undue pessimism. The choice of cruise speed should be biassed accordingly and a minimum of 0.75 M appears to be the best compromise.

- The preferred R/STOL system for the high density short haul arena has the capability of 2780 Km (1500 n.mi.) with full load and CTOL takeoff distances. This flexibility permits route scheduling on the same basis as current airplanes performing this mission; increased utilization more than compensates for the weight and cost penalties of providing the extra capability. A minimum cruise speed of 0.75 M is considered necessary for passenger acceptance in stage lengths exceeding 700 - 900 Km. (380 - 430 n.mi.).

- The choice of field length requirements for R/STOL vehicles in the short haul mode must be based on further evaluation of the land-side costs and environment. Design refinements indicate that short field lengths entail only modest DOC and fuel penalties which will potentially be more than offset by savings in real estate and congestion relief. Direct operating costs for field lengths of 610 m., 914 m. and 1220 m. (2000, 3000, 4000 ft.) aircraft are extimated to be 23%, 17% and 3% higher than for vehicles designed for 1830m. (6000 ft.) field length.

- Minimum DOC designs for R/STOL vehicles meet the postulated noise goal of FAR 36 - 15 dB but still lower noise levels cause rapidly escalating costs.

- The Sperry box 80 PNdB noise criterion is neither attainable nor appropriate to high density short haul vehicles operating from existing CTOL airports (with or without supplementary STOL runways). Similarly, a 152 m. (500 ft.) sideline measuring point is of no practical significance since it is contained within the airport boundaries. Practical attention should therefore be directed towards criteria which recognize the importance of the takeoff flyover point noise and the area of the "objectionable level" footprint which impacts the community.

R/STOL Vehicle

- In many areas a 1220 meters (4000 ft.) field length is appropriate and a twin-engine mechanical flap airplane is clearly superior to other concepts. Using engines with fan pressure ratio of 1.35 and a design cruise speed of M 0.75, its noise footprint and fuel consumption are highly attractive. For shorter field lengths, wing loadings below 400 kg/sq. m. (80 psf) are required and both ride qualities and fuel consumption become questionable. At 914 m. (3000 ft.) field length the direct operating cost with twice 1972 fuel prices is a standoff with the hybrid OTW/IBF concept.

- At field lengths of 914 m. (3000 feet) and under the hybrid OTW/IBF aircraft are recommended because of lower fuel consumption, better ride qualities, speed advantage, and potential for further improvement. The 610 m. (2000 ft.) hybrid aircraft are now estimated to have cost penalties which may be economically viable -- 25 percent increase in DOC over CTOL aircraft compared to the 50 percent penalty previously estimated.

- The augmentor wing is non-competitive with respect to both DOC and mission fuel. This conclusion is reached regardless of the degree of optimism which may reasonably be applied to the basic concept and is not changed by the alternate cruise blowing or load-compressor AW concepts.

- The externally blown flap achieves direct operating costs comparable to the basic AW and is therefore economically not competitive although it has a minimum fuel consumption of the same order as the OTW/IBF. A prime factor in this determination is the lower optimum EBF cruise speed arising from the use of a low (1.25) FPR engine to compensate for the unshielded flap interaction noise of this concept.

- The deflected slipstream (turboprop) concept appears to have an advantage with respect to both DOC and fuel consumption although the "cost superiority" indicated is obtained only if the aircraft are sized to match an existing engine (T-56). The probable development costs of a new turboprop engine indicate that such "cost savings" would in reality be either trivial or non existent. The concept shows an advantage only at design cruise speeds of less than M 0.6. It is concluded that new large aircraft would not compete successfully for passengers in stage lengths of more than 700 Km. (380 n.mi.). However, there are at least two areas in which this type of performance may have superior potential: smaller aircraft designed for shorter stage lengths in which block time and ride quality of lower wing loading would be acceptable, such as the lower density short haul where the Convair 580 and deHaviland Twin-otters are now performing so successfully; adaptation of existing aircraft to particular short stage length segments of the high density market, such as the proposed amphibian C-130.

R/STOL Propulsion

- The optimum STOL engine for both MF and OTW-IBF applications, 910 m. (3000 ft.) field length and fuel at 23¢/gal. has been shown to have a fan pressure ratio within the range 1.30 - 1.40. On the basis of the discrete engines (with some differences in fan configuration, etc.) which have provided propulsion data, a fixed pitch, 1-1/2 stage fan, 1.35 FPR engine has been preferred. The optimum FPR on a DOC basis rises to around 1.45 at the longer field lengths exceeding 1830 m. (5000 ft.) and is correspondingly reduced at the shorter distances.

- The optimum fan pressure ratio for minimum DOC at 11.5¢/gallon for fuel has been indicated to be 1.45. However, the cost advantage with respect to the 1.35 FPR engine is trivial at this now-unattainable fuel price. Moreover, the noise penalty is substantial in terms of flyover noise and more particularly, in terms of footprint area. Hence no wholly satisfactory application for this CTOL engine in a STOL vehicle can be foreseen without relaxation of the noise goal to FAR 36 - 5 dB.

- The close correlation between the minimum DOC attainable by the optimum FPR engine and that of the 1.35 FPR engine for field lengths above and below 1830 m. (6000 ft.) will improve with rising fuel prices and increasing noise constraints. Hence, CTOL applications for this "STOL engine" can be envisioned.

R/STOL Technology

- The plenum IBF duct system has been shown to be superior to the independent ducts of Reference 2 design studies and can be reconciled with stable operation of low FPR engines in parallel. The particular advantages of this arrangement include minimal duct pressure losses both in normal engine operation (no crossflow) and with sufficient crossflow for use of flap trailing edge nozzles to provide engine-out (roll) trimming. Moreover the minimal encroachment on fuel storage volume permits the use of the higher wing loadings required by minimum cost and fuel conservative vehicles.

- The use of a thick supercritical airfoil in an 0.75 Mach number application avoids significant weight and aeroelastic penalties at the high aspect ratios and low sweep angles appropriate to the fuel conservative vehicles.

11.2 RECOMMENDATIONS

The recommendations arising from this study may be summarized as follows:

- Obtain supercritical airfoil technology at speeds below 0.8 M -- since the wing depth it affords is necessary to avoid structural weight and stiffness penalties at the high aspect ratios envisioned for fuel conservative aircraft.

- Continue propulsive lift research to refine high lift technology for STOL, RTOL and CTOL rather than for early application to specific STOL designs. Additional study and R&D is needed with regard to:

  (a) Commonality of the 1.35 FPR engine for both the short haul and longer-range missions.

  (b) The fuel consumption and economics of intermediate and long range commercial aircraft related to future noise criteria.

  (c) Low wing loading aircraft for the lower density short haul arena.

  (d) Integration of the engine design with the aircraft optimization to develop a refined definition of the preferred FPR, number of fan stages, and specific fan features including gearing and fixed or variable pitch provisions.

- Increase research on gust alleviation and ride quality for mechanical flap airplanes with wing loadings of the order of 200–400 Kg/m^2 (40–80 lb./sq. ft.).

- Develop additional analyses of advanced engine characteristics for fuel conservation for which 1.35 FPR is recommended since it meets the recommended noise criteria and provides good fuel and DOC economics at both current and inflated fuel prices.

- Adopt realistic noise criteria which specifically address the impact of the airplane upon community noise at critical points in its flight path. The recommended maxima are:
  - (a) FAR 36 - 10 dB for CTOL, long range missions
  - (b) A 90 EPNdB footprint area beyond each end of the runway which does not exceed 0.65 Km^2 (0.25 sq. stat. mi.)
  - (c) A 90 EPNdB footprint which does not extend more than 1.6 Km (1 stat. mi.) beyond the runway.

- Study the land-side economics of providing terminal facilities which are compatible with the preceding noise criteria.

APPENDIX A

OTW-IBF NOISE ANALYSIS VEHICLES

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1 AND 2

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NOISE FOOTPRINT [illegible] 1.35FPR 4ENG HYBRID [illegible] 4/10/79                T1985=0     IVEC=0      ITR=1

STOL DISTANCE=3000.FT    MACH= .75   RANGE= [illegible]   PAYLOAD=  30340.LB    NO. OF SEATS=   148.

START CRUISE ALT=270[illegible].FT   SWEEP=10.0DEG   AR=10.0   CDC= 2.    COMISC=   .0    D [illegible].085

IVER=3  IMACH=4   TENG= 48  VRAPH=VA [illegible]  VRAPV=VARIABLE  STARWR= .935  SECFAC= 1.052
NO.ENG USED INIT AL CRUISE=4.   ENG COST FACTOR=1.[illegible]   IGEAR=2    IRANGE=1    ULF= 3.750
WSP   [illegible]   TWH   DR   [illegible]  AMOUNT   [illegible]2   [illegible]3   [illegible]4   [illegible]5   OWE   CL   L/D   EVR   RESV   FUEL   VRAPH
FLTIM DST23  ROC   M  T/W R  W/S R  ZF R   TWTOS  TWLG5  W/S 5   TOS   TOC  DOC1 EVRCS DOC2  DOC4   VRARV
1[illegible]5.8 102[illegible]. 12270. 1.35 1.35 12350[illegible]. 1[illegible] 965. 1.9064[illegible]. 113268. 113042. 790[illegible]0. .409 14.80 .700  3605.  10453.  1.133
1.29 34.6  1[illegible]95.   0   .371  1[illegible]9.6  1.0[illegible]   .371   .371   1[illegible]9.6  4[illegible].36  13.65 1.640 .539 1.856  2.289   .126

DRAG BUILDUP, MACH NO. =   .750
INIT AL CRUISE LIFT COEF I[illegible]   [illegible]
CDWING  CDFUS  CDPYL  CDNAT  CDHOR  CDVER  CDPROD CDRUF  CD [illegible]  CDTRM  CDMISC CDINT  CDC  CDI  CDTOT
.0[illegible]5[illegible]  .00925 .0[illegible]  .00095 .00[illegible]  .0[illegible]  .00145 .0[illegible]97 [illegible]  .0[illegible]27 .0[illegible]73 .0 592 .0276
WETTED AREA/WING AREA
WING=1.632 FUSELAGE=[illegible].53 NACELLES=1.132 PYLONS [illegible] H TAIL= .3[illegible] V TAIL= .392 STORE/[illegible]=[illegible].073

TOC/WING    SWING     AR     TAPER     FUS LEN   FUS SWET  THRUST    SHOR     SVERT     DNAC    TRVERT
 .1365   1027.98    10.[illegible]    .30    135.25   46 1.38  12 70.39   16[illegible].05   193.62    5.5     .00

 WING        WHOR        WVER        WFUS        WLG        WHYD        WSC        WP
 1374[illegible]   [illegible]62.50    1271.94    17491.52    6 91.2[illegible]    1 42.91    3428.72    8603.57
 WELEC       WAPU       WINSTR        WAV        WAC        WAT        WFUR       DUCTW
 1614.50     99[illegible].62      700.[illegible]     1250.[illegible]    2437.06    621.68    10656.0    9[illegible]4.17
 WNAC        WPYL        WOPIT       WEMTY       OW         ZFW        AMPR       GW
 4 79.6[illegible]    .0[illegible]    1937.50   7 102.99   790[illegible].39   109430.39   67[illegible]53.46   123493.06
 SWING       AR         SWEEP       WGRSS      WFUEL      PAYLD      THRUST     TAPER
 1027.98     10.0[illegible]     6.93    12350[illegible].48   14062.[illegible]7   30340.0[illegible]   12[illegible]69.[illegible]1    .30
 TCROOT      TCTIP       SHOR       SVERT      FLENGTH    FUSAREA    DELPRESS   VDIVE
 14.47       11.06      16[illegible].05     193.62     135.25     4661.38    8.90      386.43
RANGE/D.O.C. DATA
 RANGE    DOC1     DOC2     DOC4     DOC10
 [illegible]50[illegible].   1.640    1.856    2.[illegible]89    3.586

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C    FUEL50[illegible]
 53[illegible]3[illegible]6.   2904 [illegible]2.   913 [illegible]7[illegible].   10453.
DOLLARS PER NAUTICAL MILE COST OF:
 CREW     FUEL     INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
 .57[illegible]   .363    .139    .095    .082    .067    .219    .293    .907    2.795
 50[illegible].   1.640   1.856   2.[illegible]89   3.596
 [illegible]0[illegible].   1.7[illegible]5   2.010   2.490   3.890
 30[illegible].   1.9[illegible]    2.[illegible]65   2.795   4.391
 20[illegible].   2.4[illegible]7   2.7[illegible]   3.425   5.395

                      RAMP     T/O     ST.CF.    END CF.   LOWT
1[illegible]5.8 1023. 12[illegible]70. 1.35 1.35 12350[illegible]. 12 965. 1[illegible]964[illegible]. 113268. 113042. 790[illegible]. .409 14.80 .700  3605.  10458.  1.133
 1.29 3[illegible].6  1[illegible]95.   0   .371  1[illegible]9.6  1.0    .371   .371   1 9.6   4[illegible].36  13.65 1.640 .539 1.856  2. 89   .126
  1.0[illegible]   1.0[illegible]   1.0[illegible]   1.0[illegible]   1.0[illegible]   1.0[illegible]
  1.0[illegible]   1.0[illegible]   1.0[illegible]   .8[illegible]   1.0[illegible]   1.0[illegible]
  1.0[illegible]   1.0[illegible]   1.0[illegible]   1.0[illegible]   1.0[illegible]   .0[illegible]
[illegible] FROM [illegible] FROM [illegible]
[illegible] TASK UNITS=1     ACCUM T [illegible]=23     CORE=19[illegible]63     CORE SEC=174     ACCUM CPU=6     *
```

FIGURE A-1: OTW/IBF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (1)

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```
 NOISE FO TPRINT [illegible] 1.35FPR 4ENG HYBRID MIDOC4.10  4/10/74            T1985=0      IVEC=0      TTR=1

 STOL DISTANCE=30[illegible].FT    MACH= .70    RANGE= 50[illegible].NM    PAYLOAD= 30[illegible]40.LB    NO. OF SEATS=  148.

 START CRUISE ALT=30[illegible].FT.  SWE P=10.0DEG    AR=14.0[illegible]    CDO= 2.    CDMISC=    .00    D.M=.080

 IVER=8    IMACH=4    IENG= 48   VBARH=VARIABLE   VBARV=VARIABLE  ETAPWR= .93[illegible]  SFCFAC= 1.051
 NO.ENG USED INITIAL CRUISE=4.      ENG COST FACTOR=1.00[illegible]       IGEAR=2      IRANGE=1      ULF= 3.750
  WSP     S      TUN      PR  PRP   RAMPWT      W2         W3         W4         W5         OWE       CL     L/D   EVR    RESV     FUEL      VBARH
 FLTIM DST23   ROC       N  T/W R  W/S R     ZFWR        TWTO5      TWLG5      W/S 5       TOS       TOC    DOC1 EVRCS   DOC2   DOC4      VBARV
 104.[illegible] 1097. 10685. 1.35 1.35 1[illegible]94[illegible]3. 118924. 1[illegible]49[illegible]. 110158. 109.62.  76[illegible]78.  .485 17.06 .498   2927.    9481.    1.330
  1.421[illegible].3   806.    0    .334  108.4   1.0[illegible]     .3[illegible]4      .334      108.4      36.21   17.23 1.678 .402   1.875  2.267      .097

    DRAG BUILDUP, MACH NO. =     .700[illegible]
   INITIAL CRUISE LIFT COEFFICIENT=     .485
 CDWING  CDFUS  CDPYL   CDNAT  CDHOR  CDVER  CDROD CDRUFL CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
 .0[illegible]678 .0[illegible]8[illegible]1 .0[illegible]   .00073 .00[illegible]69 .0[illegible]3 .00136 .00[illegible] .00[illegible]20 .00[illegible]50 .0[illegible] .00[illegible] .02249 .0[illegible]59[illegible] .0284[illegible]
   WETTED AREA/WING AREA
 WING=1.7[illegible]2 FUSELAGE=4.251 NACELLES= .930 PYLONS= .0[illegible] H TAIL= .336 V TAIL= .359 STOT/SREF=7.64[illegible]

 TOCWING     SWING          AR        TAPER       FUS LEN    FUS SWET   THRUST      SHOR        SVERT        DNAC       TRVERT
   .1723    1096.59       14.0[illegible]          .30      136.25     46[illegible]1.38  10685.10     181.50      193.62        5.17          .00

     WING              WHOR              WVER              WFUS              WLG               WHYD              WSC               WPR
    141[illegible]2.[illegible]          [illegible]1.0[illegible]          1[illegible]98.12          17096.96          6471.42          1[illegible]17.98          3353.95          7594.65
    WELEC             WAPU              WINSTR            WAV               WAC               WAT               WFUR              DUCTW
     1586.10           893.20            70[illegible]          1250.00           2437.06            629.45          1065[illegible].0[illegible]          743.45
    WNAC              WPYL              WOPIT             WEMTY             OW                ZFW               AMPR              GW
     3890.20              .0[illegible]          1925.62          74[illegible]51.[illegible]          76[illegible]7[illegible].62         107617.62          6 39[illegible].01          1[illegible]9426.08
    SWING             AR                SWE P             WGRS              WFUEL             PAYLD             THRUST            TAPER
     1096.59             14.0[illegible]              7.35          1[illegible]94[illegible]2.[illegible]1          12468.36           30340.0[illegible]          10684.31              .30
   TCRO T            TC TIP            SHOR              SVERT             FLENGTH           FUSAREA           DELPRES           VOIVE
       18.27             13.96            181.50            193.62            136.25           46[illegible]1.38              8.80            364.01
  RANGE/D.O.C. DATA
     RANGE       DOC1        DOC2        DOC4        DOC10
      50[illegible].       1.678       1.875       2.[illegible]67       3.4[illegible]

 TOTAL COST OF
 A/C LESS ENG   TOTAL ENG   COMPLETE A/C     FUEL50
   [illegible]5012[illegible].       2671[illegible]3[illegible].       7691037.          9481.
 DOLLARS PER NAUTICAL MILE COST OF:
   CREW        FUEL        INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
     .62[illegible]        .3[illegible]4        .135        .0[illegible]9         .09[illegible]         .069         .2         .29         .237       2.860
     50[illegible].        1.678       1.375       2.[illegible]67        3.4
     40[illegible].        1.[illegible]       2.03[illegible]       2.96         3.7[illegible]2
     30[illegible].        2.[illegible]51       2.[illegible]       2.79[illegible]        4.2[illegible]3
     20[illegible].        2.51[illegible]       2.[illegible]        3.[illegible]55        5.3[illegible]7

 104.  1097. 10685. 1.35 1.35 1 94 3. 118924. [illegible] [illegible] [illegible]62.  76.78.  .485 17.06 .498   2927.   9481.   1.3[illegible]
  1.421 [illegible].3   806.     [illegible]    .3[illegible]4  108.4  1.0[illegible]      .3[illegible]4      .3[illegible]     108.4    36.21  17.23 1.678 .402  1.875  2.[illegible]67      .097
   1.0         1.0         1.0         1.0         1.0         1.0
   1.0         1.0         1.0         1.0         1.0         1.0
   1.0         1.0         1.0         1.0         1.0         1.0
 [illegible]                                                            
 [illegible]  TASK UNIT=1         NO UNIT I=32       COPE=1[illegible]58       COPE S[illegible]=173       AC [illegible]=73
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FIGURE A-2: OTW/IBF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (2)

```
NOISE FOOTPRINT RUNS 4ENG 1.25FPR HYBRID 3000FT 4/11/74                I1985=0    IVEC=0    ITR=1

STOL DISTANCE=3000.FT   MACH= .70   RANGE= 500.NM   PAYLOAD=  30340.LB   NO. OF SEATS=  148.

START CRUISE ALT=25000.FT   SWEEP=10.0DEG   AR=14.00   CDC= 2.   CDMISC=  .00   DDM=.080

IVER=8   IMACH=4   IENG= 49  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .921  SFCFAC= 1.065
NO.ENG USED INITIAL CRUISE=4.    ENG COST FACTOR=1.0000   IGEAR=2    IRANGE=1    ULF= 3.750
 WSP    S     TUN    PR  PRPP RAMPWT    W2       W3       W4       W5      OWE     CL   L/D   FVR    RESV    FUEL    VBARH
FLTIM DST23  ROC     N  T/W R  W/S R   ZFWR     TWTO5    TWLG5    W/S 5    TOS    TOC   DOC1 FVRCS  DOC2   DOC4     VBARV
136.0  889. 13671. 1.25 1.25 124859. 124295. 120953. 114454. 114245.  80111.  .505 15.75 .811   3775.  10614.   1.391
 1.34 61.7  1461.   0   .400  139.8  1.000    .400     .400    139.8   55.90  17.23 1.772 .640  1.991  2.430     .133

    DRAG BUILDUP, MACH NO. =   .7000
 INITIAL CRUISE LIFT COEFFICIENT=   .505
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI   CDTOT
.00663 .01077 .00000 .00129 .00102 .00124 .00167 .00114 .00020 .00050 .00000 .00114 .02560 .00643 .03203
  WETTED AREA/WING AREA
WING=1.740 FUSELAGE=5.241 NACELLES=1.694 PYLON= .000 H TAIL= .316 V TAIL= .412 STOT/SREF=9.433

TOCWING   SWING        AR     TAPER     FUS LEN   FUS SWET  THRUST    SHOR     SVERT     DNAC     TRVERT
  .1723   889.36      14.00      .30     136.25   4651.38  13672.42   138.67   193.62     6.51       .00

   WWNG          WHOR          WVER          WFUS           WLG          WHYD          WSC           WPP
    12906.84        757.13        1198.12      17212.04       6764.88       1151.19       3453.58       9960.10
  WELEC          WAPU        WINSTR           WAV           WAC           WAI          WFUR         DUCTW
    1624.02         901.78        700.00       1250.00       2437.06        605.22      10656.00       1028.99
   WNAC          WPYL          WOPIT         WEMTY          OW            ZFW          AMPR           GW
    5491.41           .00       2012.90      78098.35      80111.34     110451.34      67639.21     124840.76
  SWING            AR          SWEEP         WGRSS         WFUEL         PAYLD         THRUST        TAPER
     889.36        14.00          7.85     124859.32      14389.42      30340.00      13671.43           .30
  TCROOT         TCTIP          SHOR         SVERT        FLENGTH        FUSAREA       DELPRESS      VDIVE
     18.27         13.96        138.67        193.62        136.25       4651.38          8.80        364.01
 RANGE/D.O.C. DATA
   RANGE      DOC1       DOC2       DOC4       DOC10
    500.      1.772      1.991      2.430      3.747

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C     FUEL500
   5322075.    3376267.      8698343.      10614.
DOLLARS PER NAUTICAL MILE COST OF:
  CREW       FUEL       INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
    .596      .374       .210       .097      .083       .072      .271       .305      1.012      3.020
    500.     1.772      1.991      2.430     3.747
    400.     1.908      2.145      2.619     4.039
    300.     2.135      2.400      2.930     4.520
    200.     2.583      2.909      3.550     5.473

136.0  889. 13671. 1.25 1.25 124859. 124295. 120953. 114454. 114245.  80111.  .505 15.75 .811   3775.  10614.   1.391
 1.34 61.7  1461.   0   .400  139.8  1.000    .400     .400    139.8   55.90  17.23 1.772 .640  1.991  2.430     .133
   1.0000     1.0000     1.0000     1.0000     1.0000     1.0000
   1.0000     1.0000     1.0000      .8300     1.0000     1.0000
   1.0000     1.0000     1.0000     1.0000     1.0000      .0000
DOVRS 000000 FPOF 000000 FPUF 000000 FRMD 000000
***** TASK UNITS=1        ACCUM TTL=11      CORE=19068     CORE SEC=17      ACCUM CPU=17      *
```

FIGURE A-3: OTW/IBF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (3)

```
NOISE FOOTPT 4ENG 1.47FPR HYBRID  3000FT 4/11/74                          I1985=0     IVEC=0     ITR=1

STOL DISTANCE=3000.FT    MACH= .75    RANGE= 500.NM    PAYLOAD=  30340.LB    NO. OF SEATS=   148.

START CRUISE ALT=30000.FT    SWEEP=10.0DEG    AR=14.00    CDC= 2.    CDMISC=    .00    DDM=.080

IVER=8    IMACH=4    IENG= 53   VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .700  SFCFAC= 1.144
NO.ENG USED INITIAL CRUISE=4.      ENG COST FACTOR=1.0000     IGEAR=2     IRANGE=1     ULF= 3.750
 WSP     S     TUN      PR  PRPP RAMPWT     W2        W3        W4       W5        OWE      CL    L/D   FVR     RESV     FUEL     VBARH
FLTIM DST23   ROC       N  T/W R  W/S R    ZFWR     TWTO5     TWLG5    W/S 5      TOS      TOC   DOC1 FVRCS  DOC2   DOC4       VBARV
108.0 1166. 12195. 1.47 1.47 130253. 129408. 125947. 119298. 118971.  84839.  .437 17.38 .705   3732.  11281.   1.180
 1.24 40.3  3003.   0   .351  111.0    .999     .351     .351    111.0   38.98  13.32 1.606 .573  1.839  2.305       .088

    DRAG BUILDUP, MACH NO. =    .7500
 INITIAL CRUISE LIFT COEFFICIENT=    .437
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
.00584 .00821 .00000 .00057 .00098 .00095 .00128 .00090 .00020 .00050 .00000 .00090 .02034 .00483 .02517
  WETTED AREA/WING AREA
WING=1.759 FUSELAGE=3.997 NACELLES= .707 PYLON= .000 H TAIL= .307 V TAIL= .337 STOT/SREF=7.108

TOCWING    SWING        AR      TAPER      FUS LEN   FUS SWET  THRUST.    SHOR       SVERT      DNAC      TRVERT
   .1332   1166.18     14.00         .30    136.25   4661.38  12194.85    176.62    193.62      5.13        .00

   WWNG           WHOR           WVER           WFUS           WLG            WHYD           WSC            WPP
    17961.12       1023.78        1271.94        17854.73       7057.09        1183.78        3551.33        9901.26
  WELEC          WAPU          WINSTR           WAV            WAC            WAI            WFUR           DUCTW
      1661.77        910.32         700.00        1250.00        2437.06        635.19        10656.00        741.08
   WNAC          WPYL           WOPIT          WEMTY           OW             ZFW            AMPR           GW
     4029.96         .00         2012.86        82826.40       84339.25      115179.25       71905.43     130192.36
  SWING           AR           SWEEP          WGRSS          WFUEL          PAYLD          THRUST         TAPER
     1166.18       14.00          7.85        130252.72       15013.11       30340.00       12194.74         .30
  TCROOT         TCTIP          SHOR           SVERT         FLENGTH        FUSAREA        DELPRESS       VDIVE
       14.12       10.79         176.62          193.62        136.25         4661.38          8.80         386.43
 RANGE/D.O.C. DATA
   RANGE      DOC1      DOC2      DOC4      DOC10
    500.     1.606     1.839     2.305     3.704

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C     FUEL500
   5450081.     2540705.       7990787.       11281.
DOLLARS PER NAUTICAL MILE COST OF:
  CREW       FUEL       INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
    .559      .397        .180        .099       .082      .066       .195       .295       .863       2.737
    500.     1.606      1.839      2.305      3.704
    400.     1.731      1.986      2.495      4.024
    300.     1.939      2.230      2.810      4.552
    200.     2.355      2.716      3.437      5.600

108.0 1166. 12195. 1.47 1.47 130253. 129408. 125947. 119298. 118971.  84839.  .437 17.38 .705   3732.  11281.   1.180
 1.24 40.3  3003.   0   .351  111.0    .999     .351     .351    111.0   38.98  13.32 1.606 .573  1.839  2.305       .080
   1.0000     1.0000     1.0000     1.0000     1.0000     1.0000
   1.0000     1.0000     1.0000      .8300     1.0000     1.0000
   1.0000     1.0000     1.0000     1.0000     1.0000      .0000
DOVRS 000000 FPOF 000000 FPUF 000000 FRMD 000000
 ***** TASK UNITS=1         ACCUM TTL=79       CORE=19968      CORE SEC=179      ACCUM CPU=206      *****
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FIGURE A-4: OTW/IBF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (4)

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NOISE FO TPRINT 1.35FPR 4ENG HYBRID MINDOC1,2 SPLIT ERS 4/12/74 T1985=0 IVEC=0 ITR=1

STOL DISTANCE=3000.FT MACH= .75 RANGE= 500.NM PAYLOAD= 30340.13 NO. OF SEATS= 148.

START CRUISE ALT=270 .FT SWE P=10. DEG AR=10. CD= 2. COMISC= .00 DOME=.69

IVER=9 IMACH=4 IENG= 48 VBAPH=VARIABLE VBARV=VARIABLE STATE= .912 SEC = 1.065
NO.ENG USED INITIAL CRUISE=4. ENG COST FACTOR=1.0 IGEAR=2 IRANGE=1 HLF= 3.750
WSP THR PR PR AMINT W2 W3 W4 W5 ONE CL L/D FVP RESV FUEL VBARH
FLTIM DST23 ROC T/W R W/S R ZFWR TWT05 TWLG5 W/S 5 TOS TOC DOC1 FVRCS DOC2 DOC4 VBARV
1 5.8 1036. 12534. 1.35 1.35 124965. 123858. 119 . 114 35. 3905. 7986. .409 14.85 .698 36 2. 10560. 1.120
1.28 4.3 1233. 0 .37 119.5 1.00 .37 .37 119.5 4 .56 13.65—1.64—.539 —1.863 2.9 .125

DRAG BUILD UP, MACH NO. = .750
INITIAL CRUISE LIFT COEF ICIENT= .409
CDWING CDFUS CDPYL CDNAT CDHOR CDVER CDPRO CDRUF CDCOMP CDTRM CDMISC CDINT CDO CDI CDTOT
.00545 .0191 .0 .0196 .00103 .00105 .00149 .00 95 .00 .0 .0 .00096 .02163 .00592 .02756
WETTED AREA/WING AREA
WING=1.690 FUSELAGE=4.199 NACELLES=1.154 PYLONS .00 H TAIL= .325 V TAIL= .379 STO/CREF=8.047

TOCWING SWING AR TAPER FUS LEN FUS SWET THRUST SHOR SVERT DNAC TRVERT
.1365 1036.25 10. .30 136.25 4651.38 12534.69 16 .05 193.62 5.60 .0

W ING WHOR WVER WFUS WLG WHYD WSC WPP
133 7. 5 962.50 1271.94 17 14.5 6743.53 1148.79 34 6.38 87 1.77
WEL C WAPU WINSTR WAV WAC WAT WFUR DUCTW
1621.35 901. 5 70 . 1250. 2437.06 622.46 10656.0 897.59
WNAC WPYL WOPIT WEMTY OW ZFW AMPR GW
482 .73 .0 1905.02 778 1.46 7986 .43 10206.48 6834 .35 124 29.75
SWING AR SWE P WGPS WFUEL PAYLD THRUST TAPER
1036.25 10. 6.98 124 65.35 142 .26 30340. 12534.20 .30
TCRO TC IP SHOR SVERT FLENGTH FUSAREA DELPRESS VOIVE
14. 7 1 .06 15 .05 193.62 136.25 46 1.39 8. 0 386.43
RANGE/D.O.C. DAT
RANGE DOC1 DOC2 DOC4 DOC10
50 . 1.64 1.863 2. 9 3.609

TOTAL COST OF
A/C LES NG TO AL ENG COMPLET A/C FUELSOC
538 6 3. 29 5473. 821 6. 10560.
DOLLARS PER NAUTICAL MILE COST OF:
CREW FUEL INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
.571 .372 .190 .096 .032 .067 .2 0 .294 .910 2.803
500. 1.64 1.863 2.794 3.609
400. 1.778 2.015 2.490 3.912
300. 2.001 2. 63 2.804 4. 1
200. 2.456 2.774 3.450 5.39

115.8 1036. 12534. 1.35 1.35 124 65. 123858. 119 8. 1 4 35. 3905. 7986 . .409 14.85 .698 36 2. 10560. 1.120
1.29 4. 1233. 0 .37 119.5 1.0 .37 .37 1 9.5 44.56 13.65 1.644 .539 1.863 2.29 .125
1.0 1.0 1.0 1.0 1.0 1.0
1.0 1.0 1.0 .9 0 1.0 1.0
1.0 1.0 1.0 1.0 1.0 .0
ERROR ERROR ERROR
PAGE UNITS=1 AC UM TI=13 CORE=1 68 CORE SEC=171 ACCUM CPU=31 ***

FIGURE A-5: OTW/IBF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (5)

```
NOISE FOOTPRINTS 1.47 HYBRID 4ENG 3000FT W/SPLITTERS 4/15/74          I1985=0      IVEC=0

STOL DISTANCE=3000.FT   MACH= .75   RANGE= 500.NM   PAYLOAD= 30340.LB   NO. OF SEATS=  148.

START CRUISE ALT=30000.FT   SWEEP=10.0DEG   AR=14.00   CDC= 2.   CDMISC=  .00   DDM=.080

IVER=8   IMACH=4   IENG= 53  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .694  SFCFAC= 1.151
NO.ENG USED INITIAL CRUISE=4.    ENG COST FACTOR=1.0000    IGEAR=2    IRANGE=1    ULF= 3.750
 WSP    S    TUN    PR  PRP  RAMPWT    W2      W3      W4      W5      OWE     CL   L/D  FVR   RESV    FUEL   VBARH
FLTIM DST23  ROC    N  T/W R  W/S R   ZFWR    TWTO5   TWLG5   W/S 5    TOS    TOC  DOC1 FVRCS  DOC2  DOC4    VBARV
108.0 1172. 12334. 1.47 1.47 130898. 130046. 126585. 119880. 119550.  85379.  .437 17.42 .704  3764.  11348.  1.171
 1.24 40.5  3078.   0   .351  111.0   .999    .351    .351    111.0   38.92  13.32 1.610 .572  1.845  2.314    .088

   DRAG BUILDUP, MACH NO. =   .7500
 INITIAL CRUISE LIFT COEFFICIENT=   .437
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI   CDTOT
.00584 .00816 .00000 .00258 .00098 .00095 .00127 .00090 .00020 .00050 .00000 .00090 .02028 .00483 .02511
  WETTED AREA/WING AREA
WING=1.760 FUSELAGE=3.977 NACELLES= .712 PYLON= .000 H TAIL= .306 V TAIL= .336 STOT/SREF=7.090

TOCWING    SWING       AR      TAPER      FUS LEN   FUS SWET  THRUST     SHOR       SVERT       DNAC       TRVERT
  .1332   1172.08    14.00       .30      136.25    4661.38  12333.69    176.62     193.93       5.16        .00

  WING          WHOR          WVER          WFUS          WLG           WHYD          WSC           WPP
  18057.27      1023.78       1274.02       17870.23      7092.07       1187.65       3562.94       10010.30
  WELEC         WAPU          WINSTR        WAV           WAC           WAI           WFUR          DUCTW
   1600.29       911.34        700.00       1250.00       2437.06       635.71       10656.00       746.99
  WNAC          WPYL          WOPIT         WEMTY         OW            ZFW           AMPR          GW
   4279.81         .00        2017.23       83361.51      85378.74      115718.74     72326.51      130830.52
  SWING         AR            SWEEP         WGRSS         WFUEL         PAYLD         THRUST        TAPER
   1172.08       14.00          7.85        130898.39     15111.77      30340.00      12333.58          .30
 TCROOT        TCTIP         SHOR          SVERT         FLENGTH       FUSAREA       DELPRESS      VDIVE
    14.12         10.79        176.62        193.93        136.25       4661.38          8.80        386.43
 RANGE/D.O.C. DATA
   RANGE       DOC1       DOC2       DOC4       DOC10
    500.       1.610      1.845      2.314      3.721

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C     FUEL500
 5489744.      2550792.    8040536.        11348.
DOLLARS PER NAUTICAL MILE COST OF:
 CREW       FUEL      INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
   .558       .400       .181      .099      .083     .060      .195      .296      .860      2.744
    500.     1.610      1.845     2.314     3.721
    400.     1.735      1.982     2.504     4.041
    300.     1.943      2.235     2.819     4.569
    200.     2.358      2.720     3.400     5.616

108.0 1172. 12334. 1.47 1.47 130898. 130046. 126585. 119880. 119550.  85379.  .437 17.42 .704  3764.  11348.  1.171
 1.24 40.5  3078.   0   .351  111.0   .999    .351    .351    111.0   38.92  13.32 1.610 .572  1.845  2.314    .088
   1.0        1.0000     1.0        1.0        1.0        1.0
   1.0        1.0        1.0        .8 0       1.0000     1.0
   1.0        1.0        1.0        1.0        1.0        .0
DOVRS 0      FPOF 0      FPUF 0      FRMD 0
*    TASK UNITS=1      ACCUM T L=12     CORE=19 68     CORE SEC=170     ACCUM CPU=31     *
```

FIGURE A-6: OTW/IBF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (6)

APPENDIX B

MF NOISE ANALYSIS VEHICLES

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NOISE FOOTPRINT RUNS 2ENG 1.35 FPR MF MINDOC10 3000FT 4/10/74          I1985=0     IVEC=0     ITR=1

STOL DISTANCE=3000.FT   MACH= .75   RANGE= 500.NM   PAYLOAD= 30340.LB   NO. OF SEATS=  148.

START CRUISE ALT=30000.FT   SWEEP=10.0DEG   AR= 7.00   CDC= 2.   COMISC=  .00   DOM=.080

IVER=1   IMACH=4   IENG=  6  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .934  SFCFAC= 1.051
NO.ENG USED INITIAL CRUISE=2.    ENG COST FACTOR= .8000    IGEAR=0     IRANGE=1    ULF= 3.750
 WSP    S     TUN    PR  PRPP RAMPWT    W2      W3      W4      W5     OWE     CL   L/D  FVP   RESV    FUEL    VBARH
FLTIM DST23   ROC    N  T/W R  W/S R   ZFWR   TWTO5   TWLG5   W/S 5    TOS    TOC  DOC1 FVRCS DOC2   DOC4    VBARV
 55.2 2409. 28544. 1.35 1.35 138000. 137317. 132969. 126482. 126204.  91860.  .224 13.03 .149  4012.  1 7  .   .823
 1.33 82.0  1255.   0   .379  57.0  1.000    .379    .379    57.0   21.60 15.85 1.595 .121  1.837  2.32     .105

   DRAG BUILDUP, MACH NO. =   .7500
 INITIAL CRUISE LIFT COEFFICIENT=   .224
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI   CDTOT
.00540 .00397 .00006 .00025 .00128 .00107 .00062 .00 64 .00021 .00350 .0 00 .00 64 .01453 .00257 .01715
  WETTED AREA/WING AREA
WING=1.777 FUSELAGE=1.935 NACELLES= .292 PYLON= .023 H TAIL= .438 V TAIL= .407 STOT/SREF=4.873

TOCWING    SWING        AR     TAPER     FUS LEN   FUS SWET  THRUST    SHOR      SVERT       DNAC      TRVERT
 .1585   2408.86      7.00       .30     136.25   4661.38  28543.28   520.32   482.5        8.14        .00

  WING          WHOR          WVER          WFUS           WLG           WHYD          WSC           WPD
   18963.28      3016.06       3170.08       21066.85       5796.02        870.31       2634.00      1 783.92
  WELEC         WAPU        WINSTR           WAV           WAC           WAI          WFUR          DUCTW
   1716.00      1048.40        70 .00        1250.0        2437.06        739.64       10655.00        .00
  WMAC          WPYL          WOPIT         WEMTY          OW            ZFW           AMPR          GW
   1981.05      1961.88       2060.03       89700.49       91859.51      122199.51     74731.76      137997.71
 SWING           AR          SWEEP         WGRSS          WFUEL         PAYLD         THRUST        TAPER
   2408.86        7.00           5.68      138000.41       1578 .20      30340.0       28543.65        .30
 TCROOT        TCTIP         SHOR          SVERT         FLENGTH       FUSAREA       DFLPRES       VOL F
     16.80        12.84       520.32        482.55        136.25        46 1.38         8.30        396.43
 RANGE/D.O.C. DATA
   RANGE     DOC1      DOC2      DOC4      DOC10
   500.      1.595     1.837     2.325     3.781

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C    FUEL50
   5553049.    1884291.     7437340.     1177 .
DOLLARS PER NAUTICAL MILE COST OF:
  CREW      FUEL      INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TO AL
   .593      .414      .178      .109      .086      .054      .150      .290      .842      2.717
   500.     1.595     1.837     2.323     3.781
   400.     1.730     1.995     2.523     4.100
   300.     1.956     2.256     2.850     4.652
   200.     2.407     2.776     3.513     5.727

 55.2 2409. 28544. 1.35 1.35 138000. 137317. 132969. 126482. 126 04.  91860.  .224 13.03 .148  4012.  1 7  .   .423
 1.33 82.0  1255.   0   .379  57.0  1.000    .379    .379    57.0   21.60 15.85 1.595 .121  1.837  2.323     .105
   1.000    1.0 00    1.000    1.0      1.0000   1.0
   1.0000   1.00      1.0 00   1.00     1.0      1.000
   1.0      1.0000    1.00     1.0000   1.0000   1.0000
DOVRS 00    FPOF 000    FPUF 00    ERMD 0000
*      TASK UNITS=1        ACCUM TTL=28      CORE=19 68     CORE SEC=175      AC UM COR=71      *
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FIGURE B-1: MF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (1)

```
NOISE FOOTPRINT RUNS 2ENG 1.35 FPR MF MINDOC10 30[illegible]FT 4/10/74          I1985=0      IVEC=0      ITR=1

STOL DISTANCE=30[illegible].FT   MACH= .70   RANGE= 50[illegible].NM   PAYLOAD= 30[illegible].LB   NO. OF SEATS=  148.

START CRUISE ALT=330[illegible].FT   SWEEP=10.[illegible]DEG   AR=10.0[illegible]   CDC= 2.   CDMISC=  .0   D M=.08[illegible]

IVER=1   IMACH=4   IENG= 6  VBARH=VARIABLE  VBARV=VARIABLE  ETARWR= .936  SFCFAC= 1.048
NO.ENG USED INITIAL CRUISE=2.   ENG COST FACTOR= .80[illegible]   IGEAR=0   IRANGE=1   ULF= 3.750
 WSP    S    TUN    PR  PPP  RAMPWT    W2      W3      W4      W5      OWE     CL    L/D   EVP   RESV   FUEL   VBARH
FLTIM DST23  ROC    N  T/W R  W/S R   ZFWR    TWT05   TWLG5   W/S 5    TOS    TOC   DOC1 EVPCS  DOC2  DOC4   VBARV
 5[illegible].7 2319. 2628[illegible]. 1.35 1.35 134527. 13[illegible]898. 129146. 124168. 1239[illegible]. 90350. .297 15.71 .146  32[illegible]7.  10597.  .925
 1.44106.1  956.   0  .358   57.7  1.0[illegible]   .358   .358    57.7  20.67 17.23 1.623 .12[illegible] 1.842  2.[illegible]79   .10[illegible]

 . DRAG BUILDUP, MACH NO. =   .70[illegible]
 INITIAL CRUISE LIFT COEFFICIENT=   .297
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDROU CURUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI   CDTO
.00617 .00419 .00[illegible]6 .00025 .0[illegible]11[illegible] .00127 .00064 .0[illegible]69 .0[illegible]29 .[illegible]5[illegible] .[illegible]  .[illegible]69 .01572 .0[illegible]312 .01901
 WETTED AREA/WING AREA
WING=1.826 FUSELAGE=2.010 NACELLES= .280 PYLONS .02[illegible] H TAIL= .358 V TAIL= .873 STOT/SREF=4.270

TOCWING    SWING        AR     TAPER    FUS LEN  FUS SWET  THRUST     SHOR      SVERT      DMAC     TDVE[illegible]
 .1723   2318.60     10.0[illegible]      .30    136.25   46[illegible]1.38  26[illegible]9.9[illegible]   409.38    540.72      7.81      .0[illegible]

  WWING        WHOR        WVER        WFUS        WLG         WHYD        WSC         WP
  20248.[illegible]      2[illegible]35.27     3[illegible]46.04    20389.[illegible]    5650.13      863.[illegible]     2500.[illegible]8    10997.01
 WELEC         WAPU        WINSTR      WAV         WAC         WAI         WFUR        WDUCT
  1691.69     1042.15      700.0      1250.[illegible]    2437.06      728.96     1065[illegible]     [illegible].0
 WNAC          WPYL        WOPIT       WEMTY       OW          ZFW         AMOD        GW
  1821.52     1805.37     19[illegible]6.1[illegible]    8[illegible]354.10    90350.21   120690.21    7805[illegible].[illegible]3   1345[illegible].23
 SWING         AR          SWE D       WGRS        WFUEL       PAYLD       THRUST      TAPER
  2318.60      10.           6.98    134526.93   13824.03     30[illegible]4[illegible].    26[illegible]9[illegible].32       .30
 TCROOT       TCTIP        SHOR        SVERT       FLENGTH     FUSAREA     DELDREF     VDIVE
   18.27       13.96      409.38      540.72      136.25      46[illegible]1.38     [illegible]      360.01
RANGE/D.O.C. DATA
  RANGE      DOC1      DOC2      DOC4      DOC10
  500.      1.623     1.842     2.[illegible]79     3.591

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C    FUEL50
  5272045.    1830782.     7102827.      10597.
DOLLARS PER NAUTICAL MILE COST OF:
 CREW      FUEL      INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MAINCE BURDEN DEPRECIATION TOTAL
  .639     .37[illegible]      .185      .1[illegible]2      .085      .054      .154     .299     .960    2.7[illegible]
  500.     1.623     1.842     2.279     3.591
  400.     1.761     2.0[illegible]     2.485     3.[illegible]2
  30[illegible].    1.9[illegible]0     2.[illegible]60     2.8[illegible]5     4.[illegible]95
  20[illegible].    2.4[illegible]     [illegible].9[illegible]     3.504     5.61[illegible]

 5[illegible].7 2319. 26[illegible]. 1.35 1.35 [illegible]4527. 13[illegible]89[illegible]. 129146. 12[illegible]68. 1230[illegible]. [illegible] .[illegible]97 [illegible] [illegible]  3[illegible]7.  10[illegible]7.   .925
 1.44106.1   956.  [illegible]0   .358   57.7  1.0[illegible]   .358   .358    57.   20.67 17.2[illegible] [illegible] [illegible]  2.[illegible]79   .10[illegible]
  1.0[illegible]     1.0[illegible]     1.0     1.0     1.0[illegible]     1.0[illegible]
  1.0[illegible]     1.0[illegible]     1.0     1.0     1.0     1.0[illegible]
  1.0[illegible]     1.0     1.0     1.0     1.0     1.0
DOVRS 0[illegible]  EDOC [illegible]   EDOE [illegible]   EDMD [illegible]
 [illegible]  TACK [illegible]   AC [illegible]   COFE=10.68   [illegible]
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FIGURE B-2: MF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (2)

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NOISE FOOTPRINT RUNS 2ENG 1.35 FPR MF MINDOC2 40  FT 4/10/74          I1985=0     IVEC=0      ITP=1

STOL DISTANCE=4000 .FT   MACH= .75   RANGE= 500.NM   PAYLOAD= 30340.LB   NO. OF SEATS=

START CRUISE ALT=300 0.FT   SWEEP=10.0DEG.  AR=10.0    CDC= 2.   CDMISC=   .00   DOM=.080

IVEP=1   IMACH=4   IENG=  6   VBARH=VARIABLE   VBARV=VARIABLE   ETAPWR= .850  SFCFAC= 1.095
NO.ENG USED INITIAL CRUISE=2.     ENG COST FACTOR= .80       IGEAR=0     IRANGE=1     ULF= 3.750
 WSP    S     TUN      PR   PPR   RAMPWT     W2        W3        W4       W5        OWE      CL     L/D    FVR   RESV      FUEL     VBARH
FLTIM DST23  ROC       N  T/W P  W/S P   ZFWR     TWTO5     TWLG5     W/S 5      TOS     TOC    DOC1 FVPCS  DOC2    DOC4      VBARV
 78.3 1511. 23971. 1.35 1.35 122284. 121710. 118321. 112983. 112766.  79198.  .317 15.17 .317   3212.    9519.     .830
 1.30 68.  1520.    0   .359   80.5  1.00      .359     .359     80.5   28.92  14.54 1.455 .255  1.641  2.034      .085

   DRAG BUILDUP, MACH NO. =    .7500
 INITIAL CRUISE LIFT COEFFICIENT=    .317
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPRO CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO     CDI  CDTOT
.00559 .00633 .0  08 .00134 .0 092 .0 087 .00 98 .00077 .0 020 .0  50 .000   .00077 .01734 .00356 .02090
  WETTED AREA/WING AREA
WING=1.754 FUSELAGE=3.085 NACELLES= .391 PYLON= .031 H TAIL= .291 V TAIL= .311 STOT/SREF=5.864

TOCWING     SWING          AR     TAPER       FUS LEN    FUS SWET   THRUST     SHOR        SVERT         DNAC       TRVERT
  .1454     151 .12       10.00          .30    136.25    46 1.38   23972.55   216.8      231.32          7.46          .0

   WING          WHOR         WVER          WFUS          WLG          WHYD           WSC           WPP
   14126.03       1257.13       1519.63       20697.97      5135.93        810.95        2432.84        9629.22
 WELEC          WAPU         WINSTR          WAV          WAC          WAT           WFURN         DUCTW
   1605.90       1020.11        70 .00        1250.0       2437.06       6  .05       10656.00          .00
  WNAC          WPYL         WOPIT         WEMTY         OW           ZFW           AMPR          GW
   1657.86       164 .68       1950.33       7 248.06     79198.30     109538.39      67964.81      122 68.82
 SWING           AR          SWEEP          WGPS          WFUEL        PAYLD         THRUST        TAPER
   151 .12        10.0           6.98       122 84.14     12730.43     30340.0       23970.58         .30
 TCROOT        TCTIP         SHOR          SVERT        FLENGTH       FUSAREA       DELPRES       VDIVE
   15.41         11.78         216.83        231.32       136.25       4661.38          8.80          386.43
RANGE/D.O.C. DATA
  RANGE       DOC1       DOC2       DOC4       DOC10
  500.        1.455      1.641      2.034      3.212

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C     FUEL500
  5106804.    1772585.    6879389.          9519.
DOLLARS PER NAUTICAL MILE COST OF:
 CREW     FUEL      INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
  .580     .305      .161      .096      .078      .048      .140      .259      .755      2.462
  500.    1.455     1.641     2.034     3.212
  400.    1.564     1.778     2.206     3.491
  300.    1.761     2.095     2.491     3.950
  200.    2.156     2.457     3.059     4.863

 78.3 15 . 23971. 1.35 1.35 122 84. 121710. 118321. 112983. 112766.  791 8.  .317 15.17 .317   3212.   9519.    .830
 1.30 68.  1520.    0  .359   80.5  1.00     .359     .359     80.5   28.92  14.54 1.4 5 .255  1.641  2.034     .085
  1.000     1.000     1.000     1.0 00     1.000     1.0  1
  1.0 00    1.00      1.0 00    1.00      1.0000    1.000
  1.0 00    1.000     1.0       1.000     1.00      1.0 00
DOVPF 00     EPOF 000    EPUF 000    ERMD 000
*     TASK UNITS=1        ACCUM TTL=32      COPE=19 468     COPE SEC=793      ACCUM CPU=84      ****
```

FIGURE B-3: MF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (3)

```
NOISE FO TPRINT RUNS 2ENG 1.35 FPR MF MINDOC2 6000FT 4/10/74          I1995=0     IVEC=0     ITR=1

STOL DISTANCE=6000.FT   MACH= .75   RANGE= 500.NM   PAYLOAD=  30340.LB   NO. OF SEATS=  148.

START CRUISE ALT=2700 .FT   SWEEP=10.0DEG   AR=10.00   CDC= 2.   CDMISC=  .00   DDM=.080

IVER=1   IMACH=4   IENG= 6  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .934  SFCFAC= 1.051
NO.ENG USED INITIAL CRUISE=2.     ENG COST FACTOR= .8000     IGEAR=0     IRANGE=1     ULF= 3.750
 WSP    S     TUN     PR   DROO RAMPWT     W2        W3        W4        W5       OWE     CL    L/D   EVR    RESV     FUEL     VBARH
FLTIM DST23  ROC     N   T/W R  W/S P    ZFWR      TWTO5     TWLG5     W/S 5     TOS     TOC   DOC1 EVRCS  DOC2   DOC4      VBARV
 90.3 1256. 20305. 1.35 1.35 117323. 116837. 113437. 108249. 108065.  74496.  .319 14.16 .420   3210.    9258.   1.013
 1.31 80.9  1148.    0   .317   93.0  1.000    .317     .317     93.0   29.47  14.52 1.408 .332  1.590  1.981     .094

   DRAG BUILDUP, MACH NO. =   .7500
 INITIAL CRUISE LIFT COEF ICIENT=   .319
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
.00500 .00758 .00008 .00035 .00101 .00087 .00118 .00084 .00029 .00150 .00000 .00084 .01894 .00360 .02255
  WET FD AREA/WING AREA
WING=1.726 FUSELAGE=3.711 NACELLES= .390 PYLON= .032 H TAIL= .324 V TAIL= .313 STOT/SREF=6.505

TOCWING     SWING        AR      TAPER      FUS LEN    FUS SWET   THRUST     SHOR      SVERT      DNAC      TRVERT
  .1452   1256.23      10.00       .30      136.25    4601.38   20308.32    209.61    193.62      6.87       .00

   WING          WHOR          WVER           WFUS           WLG           WHYD          WSC           WP
  12985.94      1 62.85       1271.94        20572.27       4927.57        789.08       2367.24       8137.60
  WELEC         WAPU        WINSTR           WAV            WAC           WAI           WFUR          DUCTW
   1571.26      1011. 8        70 .0          1250.00        2437.06        644.83       10656.00        .00
  WNAC          WPYL          WOPIT          WEMTY           OW            ZFW           AMPR           GW
   139 .71      1390.89       1920.19        72575.48      74 95.6       104835.60      64517.10      117313.42
  SWING          AR           SWEEP          WGRSS          WFUEL         PAYLD         THRUST        TAPER
   1256.23      10.00           6.98        117323.15      12477.76       30340.00      20305.26        .30
  TCRO T        TCTIP         SHOR           SVERT          FLENGTH       FUSAREA       DELPRESS      VDIVE
    15.30       1 .76        209.61          193.62         136.25        4601.38         8.30        386.43
 RANGE/D.O.C. DATA
   RANGE       DOC1       DOC2       DOC4       DOC10
    50 .      1.408      1.590      1.981      3.127

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C      FUEL500
   496 34 .    1672564.     6 38907.        9258.
DOLLARS PER NAUTICAL MILE COST OF:
  CREW      FUEL      INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
    .582     .326      .157      .093      .077      .043     .132      .245      .740     2.39
    50 .    1.408     1.590     1.981     3.127
    40 .    1.526     1.73      2.108     3.39
    30 .    1.72      1.957     2.425     3.831
    20 .    2.1 5     2.402     2.977     4.70

 90.3 1256. 20305. 1.35 1.35 1 732 . 1 6837. 113437. 108249. 108065.  74 96.  .319 14.16 .420   3210.   9258.  1.013
 1.31 80.9  1 48.    0   .317   93.0  1.00     .317     .317     93.0   29.47  14.52 1.408 .332  1.590  1.981     .094
   1.0        1.0      1.00       1.0       1.0       1.0
   1.0        1.0      1.00       1.0       1.0       1.0
   1.00       1.0      1.0        1.0       1.0       1.0
HOURS 0      EROE 0      EOE 0      EDME 0
 +    TASK UNITS=1       AC UN T =35      CORE=19 68     CORE E C=173       ACTUM C =95      +
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FIGURE B-4: MF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (4)

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NOISE FOOTPRINT 4ENG 1.35FPR MF 400 FT MINDOC2 4/12/74                I1985=0     IVEC=0     ITR=1

STOL DISTANCE=3000.FT    MACH= .75    RANGE= 500.NM    PAYLOAD=  30340.LB    NO. OF SEATS=   148.

START CRUISE ALT=27000.FT    SWEEP=10.0DEG    AR=10.0    CDC= 2.    CDMISC=   .00    DDM=.08

IVER=1   IMACH=4   IENG=  6  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .934  SFCFAC= 1.051
NO.ENG USED INITIAL CRUISE=4.     ENG COST FACTOR=1.000      IGEAR=2     IRANGE=1     ULF= 3.750
 WSP    S     TUN     PR   PRPP RAMPWT     W2       W3       W4       W5      OWE     CL    L/D   FVR    RESV     FUEL     VBARH
FLTIM DST23  ROC      N   T/W R  W/S R    ZFWR     TWTO5    TWLG5    W/S 5    TOS     TOC   DOC1 FVRCS  DOC2   DOC4      VBARV
 80.2 1427. 10490. 1.35 1.35 118194. 117692. 114427. 108907. 108807.  75146.  .283 13.82 .340   3320.    9387.     .894
 1.30 75.2  1265.    0   .325   82.5  1.000     .325     .325     82.5   26.81  14.82 1.571 .273  1.765  2.153      .084

    DRAG BUILDUP, MACH NO. =    .7500
 INITIAL CRUISE LIFT COEFFICIENT=    .283
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
.00561 .00607 .00  8 .00033 .00 94 .00 82 .0014 .00 78 .00 2  ..   5  .00     .0  78 .01767 .00284 .02 51
  WETTED AREA/WING AREA
WING=1.747 FUSELAGE=3.267 NACELLES= .363 PYLON= .029 H TAIL= .305 V TAIL= .290 STOT/SREF=6.010

TOCWING    SWING        AR      TAPER      FUS LEN    FUS SWET  THRUST    SHOR      SVERT      DNAC     TRVERT
  .1482   1426.77      10.00       .30      136.25    4601.38  10491.49   214.30    209.03      4.99       .0

   WWNG          WHOR          WVER          WFUS           WLG           WHYD          WSC           WP
   13840.12       1242.20       1379.13       17571.19       6403.76        792.04        2378.53       8459.0
  WFLEC          WAPU         WINSTR           WAV            WAC           WAI          WFUR          DUCTW
    1577.36       1012.75        700.0        1250.0         2437.06        659.52       1065..          .0
   WNAC          WPYL          WOPIT         WEMTY            OW            ZFW           AMPR          GW
    1427.29       1427.69       1930.27       73215.28       75145.06      105485.06      65021.83     1 8191.01
  SWING           AR          SWEEP          WGRSS          WFUEL          PAYLD         THRUST        TAPER
    1426.77        10.00          6.98      118194.19       12706.35       30340.0       10491.35       .30
  TCROOT        TCTIP         SHOR          SVERT         FLENGTH         FUSAREA       DELPRES       VDIVE
     15.71        12.01        214.30        209.03         136.25        4601.38         8.0          336.43
 RANGE/D.O.C. DATA
   RANGE      DOC1       DOC2       DOC4      DOC10
    500.     1.571      1.765      2.153      3.518

TOTAL COST OF
A/C LESS ENG   TOTAL ENG   COMPLETE A/C      FUEL500
   4988331.     2654817.     7643198.         9387.
DOLLARS PER NAUTICAL MILE COST OF:
  CREW      FUEL       INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
    .580      .351       .186      .093      .17        .064       .209      .28         .862      2.57
    500.     1.571      1.765     2.153     3.518
    400.     1.701      1.91      2.302     3.593
    300.     1.918      2.15      2.628     4.097
    200.     2.351      2.641     3.216     4.907

 80.2 1427. 10490. 1.35 1.35 118194. 117692. 114427. 108907. 108807.  75146.  .283 13.82 .340   3320.    9387.     .894
 1.30 75.2  1265.    0   .325   82.5  1.00      .325     .325     82.5   26.81  14.82 1.571 .273  1.765  2.153      .084
   1.00      1.0        1.0        1.0        1..        1..
   1.00      1.0        1.0        1.0        1..        1.0
   1.0       1.0        1..        1.0        1..        1.0
DOVRS 0    . FPOF 1      FPUF 1       FRMD .
 *     TASK UNITS=1      ACCUM TIL=7      CORE=19 63     CORE SEC=186      ACCUM CPU=1        *
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FIGURE B-5: MF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (5)

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 NOISE FOOTPRINTS 4ENG 1.25FPR MF 4000FT MINDOC2 4/12/74                    I1985=0     IVEC=0     ITR=1

STOL DISTANCE=4000.FT    MACH= .65    RANGE= 500.NM   PAYLOAD=  30340.LB   NO. OF SEATS=   148.

START CRUISE ALT=25000.FT   SWEEP=10.0DEG   AR=10.00   CDC= 2.   CDMISC=   .00   DOM=.080

IVER=1    IMACH=4    IENG= 49  VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .937  SFCFAC= 1.050
NO.ENG USED INITIAL CRUISE=4.    ENG COST FACTOR=1.0000     IGEAR=2     IRANGE=1     ULF= 3.750
 WSP    S     TUN     PR  PRPP RAMPWT     W2       W3       W4       W5      OWE     CL    L/D  FVR   RESV    FUEL    VBARH
FLTIM DST23  ROC     N  T/W R  W/S R    ZFWR     TWTO5    TWLG5    W/S 5    TOS.    TOC   DOC1 FVRCS DOC2   DOC4    VBARV
 80.2 1379. 10441. 1.25 1.25 114174. 113749. 110565. 105453. 105296.  71875.  .345 14.93 .290   3035.   8377.    .942
 1.45 76.3  1114.   .0  .323   82.5   1.000    .323     .323     82.5   26.61  17.23 1.703 .232  1.837  2.255    .084

   DRAG BUILDUP, MACH NO. =    .6500
 INITIAL CRUISE LIFT COEFFICIENT=    .345
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
.00610 .00701 .00010 .00041 .00100 .00083 .00108 .00084 .00020 .00050 .00000 .00084 .01891 .00421 .02312
  WETTED AREA/WING AREA
WING=1.756 FUSELAGE=3.381 NACELLES= .435 PYLON= .035 H TAIL= .316 V TAIL= .294 STOT/SREF=6.216

TOCWING    SWING      AR    TAPER     FUS LEN   FUS SWET  THRUST     SHOR      SVERT     DNAC      TRVERT
  .1723   1378.61    10.00      .30    136.25   4661.38  10441.35   214.30    199.39     5.36        .00

    WWNG           WHOR          WVER           WFUS           WLG           WHYD           WSC           WPP
   12220.95       1098.01       1157.84       16443.47       6185.92        775.04        2325.11       8154.99
  WELEC          WAPU         WINSTR           WAV           WAC            WAI           WFUR          DUCTW
    1549.21       1005.51        700.00        1250.00       2437.06        655.80       10656.00          .00
   WNAC          WPYL          WOPIT          WEMTY           OW            ZFW           AMPR            GW
    1907.51       1444.18       1908.35       69966.60      71874.95     102214.95      61702.42     114127.35
  SWING           AR          SWEEP          WGRSS          WFUEL          PAYLD         THRUST         TAPER
    1378.61         10.00          6.98      114173.53      11912.40      30340.00       10441.16          .30
  TCROOT        TCTIP          SHOR          SVERT         FLENGTH        FUSAREA       DELPRESS        VDIVE
      18.27         13.96        214.30        199.39        136.25       4661.38          8.80        341.58
 RANGE/D.O.C. DATA
   RANGE      DOC1      DOC2      DOC4      DOC10
    500.     1.703     1.837     2.255     3.357

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C     FUEL500
   4658537.    3076447.      7734984.       8377.
DOLLARS PER NAUTICAL MILE COST OF:
 CREW       FUEL      INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
    .636      .313      .200      .094      .075      .068      .259      .291      .966      2.903
    500.     1.703     1.837     2.255     3.357
    400.     1.831     2.030     2.428     3.622
    300.     2.044     2.268     2.716     4.060
    200.     2.469     2.742     3.289     4.928

 80.2 1379. 10441. 1.25 1.25 114174. 113749. 110565. 105453. 105296.  71875.  .345 14.93 .290   3035.   8377.    .942
 1.45 76.3  1114.   .0  .323   82.5   1.000    .323     .323     82.5   26.61  17.23 1.703 .232  1.837  2.255    .084
   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
   1.0000    1.0000    1.0000    1.0000    1.0000    1.0000
DOVRS 000000 FPOF 000000 FPUF 000000 ERMD 000000
***** TASK UNITS=1          ACCUM TTL=10       CORE=19968      CORE SEC=180      ACCUM CPU=19       *****
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FIGURE B-6: MF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (6)

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NOISE FOOTPRINT 4ENG 1.47FPR MF 400 FT MINDOC2 4/12/74                     I1985=0     IVEC=0     ITR=1

STOL DISTANCE=4000.FT    MACH= .75    RANGE= 500.NM    PAYLOAD=  30340.LB    NO. OF SEATS=   148.

START CRUISE ALT=33000.FT    SWEEP=10.0DEG    AR=14.00    CDC= 2.    CDMISC=   .00    DDM=.080

IVER=1    IMACH=4    IENG= 53   VBARH=VARIABLE  VBARV=VARIABLE  ETAPWR= .833  SFCFAC= 1.060
NO.ENG USED INITIAL CRUISE=4.    ENG COST FACTOR=1.00       IGEAR=2     IRANGE=1   ULF= 3.750
 WSP     S     TUN     PR   PRPP RAMPWT     W2        W3        W4       W5       OWE      CL    L/D   FVR   RESV     FUEL     VBARH
FLTIM DST23   ROC      N   T/W R  W/S R    ZFWR     TWTO5     TWLG5    W/S 5     TOS      TOC   DOC1 FVRCS  DOC2    DOC4      VBARV
 79.7 1493.  9757. 1.47 1.47 123800. 123124. 118906. 114054. 113793.  80391.   .370 17.31 .394  3043.   10067.    .992
 1.30 78.9  1601.    0.  .292   82.5  1.00      .292      .292      82.5    24.12  13.94 1.557 .328  1.764  2.178      .084

   DRAG BUILDUP, MACH NO. =    .7500
 INITIAL CRUISE LIFT COEFFICIENT=    .370
CDWING  CDFUS  CDPYL  CDNAI  CDHOR  CDVER  CDPOD CDRUFF CDCOMP  CDTRM  CDMISC CDINT   CDO    CDI  CDTOT
.00595 .00645 .00016 .00024 .00094 .00101 .00100 .00079 .00020 .00050 .00000 .00079 .01793 .00346 .02139
  WETTED AREA/WING AREA
WING=1.795 FUSELAGE=3.122 NACELLES= .224 PYLON= .020 H TAIL= .292 V TAIL= .363 STOT/SREF=5.815

TOCWING    SWING        AR      TAPER       FUS LEN   FUS SWET  THRUST     SHOR      SVERT      DNAC     TRVERT
  .1394   1493.04      14.00       .30      136.25    4661.38   9757.08    214.98    266.65      4.41       .00

   WWNG          WHOR          WVER          WFUS           WLG          WHYD           WSC          WPP
   17640.52      1246.13       1751.71       17712.48       6707.49       817.57        2452.71       8966.79
  WFLEC         WAPU         WINSTR          WAV           WAC           WAI          WFUR          DUCTW
    1616.60      1022.84        700.00        1250.00       2437.06       654.57       10655.00          .00
  WNAC          WPYL          WOPIT         WEMTY          OW            ZFW          AMPR           GW
    1359.41      1457.50       1932.14       78459.36      80391.50     110731.50     69385.81     123781.52
  SWING          AR           SWEEP         WGRSS         WFUEL         PAYLD         THRUST        TAPER
    1493.04        14.00          7.85      123800.02     13050.02      30340.00      9757.05          .30
  TCROOT        TCTIP         SHOR          SVERT        FLENGTH       FUSAREA       DELPRESS       VDIVE
      14.78        11.29        214.98       266.65       136.25       4661.38         8.80        386.43
 RANGE/D.O.C. DATA
   RANGE     DOC1      DOC2      DOC4      DOC10
    500.     1.557     1.764     2.178     3.419

TOTAL COST OF
A/C LESS ENG  TOTAL ENG  COMPLETE A/C      FUEL500
   5085173.    2349932.     7435105.      10067.
DOLLARS PER NAUTICAL MILE COST OF:
  CREW      FUEL       INSURANCE A/C LABOR A/C MATL ENG LABOR ENG MATL MTNCE BURDN DEPRECIATION TOTAL
   .581      .353       .175      .098      .178      .062      .185      .287      .835      2.654
   500.     1.557      1.764     2.178     3.419
   400.     1.683      1.914     2.372     3.749
   300.     1.893      2.164     2.694     4.282
   200.     2.326      2.602     3.315     5.352

 79.7 1493.  9757. 1.47 1.47 123800. 123124. 118906. 114054. 113793.  80391.   .370 17.31 .394  3043.   10067.    .992
 1.30 78.9  1601.    0.  .292   82.5  1.00      .292      .292      82.5    24.12  13.94 1.557 .328  1.764  2.178      .084
   1.000     1.00      1.00      1.0       1.00      1.000
   1.000     1.000     1.0       1.00      1.0       1.0
   1.00      1.00      1.0       1.0       1.0       1.0
DOVRS 0      FPOF 1       FPUF 0          FRMD 1
*     TASK UNITS=1         ACCUM TTL=14       CORE=19 68      CORE SFC=179      ACCUM CPU=31       *
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FIGURE B-7: MF COMPUTER SIZING DATA: NOISE ANALYSIS VEHICLES (7)

APPENDIX C

TURBOPROP MAINTENANCE

A brief assessment has been attempted to compare the maintainability, reliability and maintenance cost characteristics of the turboprop relative to those of turbofan engines. The prime differences between the turboprop and the turbofan are of course the gearbox and propellor; consequently the characteristics of these units are of prime concern. The T-56 unit was selected for this survey because of its diverse and long term usage. It was found that, while numerous records are readily available from various commercial and military operators, differences in record keeping procedures and accountability make it impossible to draw definitive statistical conclusions that encompass all users. In some cases, the operator identifies only the power-plant which includes the shaft engine, gearbox and propellor; some identify the propellor separately and some identify all three units. In some cases, an operator is not consistant throughout all of his own records. Direct comparison with turbojet/turbofan engines is also complicated by basic differences in missions which inherently produces differences in statistics.

From the material surveyed, there is evidence to support several significant observations relative to the turboprop, although with some qualifications:

- o The basic turboprop MTBO is comparable to that of the turbofan.
- o The premature removal rate is slightly higher per flight hour but lower per flight than the turbofan.
- o Mission aborts are higher per flight hour but lower per flight than the turbofan.
- o The basic shaft engine component of the turboprop has better reliability than the turbofan.
- o The propellor system accounts for approximately 25 to 40 percent of the aborts and premature removals.

- o Gearbox MTBO and reliability is generally comparable to that of the basic shaft engine component.

The MTBO of the turboprop is largely a function of the operator and his preventative maintenance, inspection and mission characteristics. Higher MTBO's may be acceptable if higher premature removal, flight shutdown and abort rates can be tolerated. Compressor TBO's range from approximately 4000 to 8000 + flight hours with the predominance in the higher range. This is comparable to the turbofan engines. The gearbox generally falls into the same TBO range as the compressor. The upper limit on turbine and propeller TBO for the T56 is around 5000 to 5500 hours with propellor inspections at half that period. The MTBO of the turbine is more representative of an older engine technology than reflecting any turboprop characteristic. The Commercial and USAAF turboprops usually operate on shorter range missions than do the turbofans thus entailing more engine starts and take-offs per turboprop flight hour than per turbofan flight hour. The increased incidence of starts and takeoffs with the attendant high TIT would be expected to take its toll on turbine life and TBO. Overhaul costs are somewhat obscure partially due to differences in methods of keeping records. One airline indicated overhaul costs on the gearbox were 5% of the total for the shaft engine and gearbox combination. No comparable figures were available for the propellor. USAAF figures indicated a total logistic support cost for the QEC, excluding the propellor system, amounts to approximately 10% of the total airplane support with the gearbox comprising approximately 17% of the QEC logistics support costs. The propellor cost amounted to an additional 55% of the QEC cost. Comparative figures are not readily available for turbofan engines.

The premature removals indicate a rate per flight hour for the T56 QEC excluding the propellor to be significantly lower than that of typical turbofans. The premature removal rates, including the propellor was slightly higher than those of the turbofans. The propellor accounted for approximately one fourth of the premature turboprop removals. Premature removals due to the gearbox are not well identified but the indications are that the gearbox necessitated about 20% of the QEC removals with about half of these associated with accessory drives on the gearbox. The gearbox record would be improved if these accessories were mounted on the shaft engine section but it is unlikely that this would alter the over-all record. The gearbox is of course charged with malfunctions that occur in these accessory drives which probably accounts in part for the shaft engine section appearing to be significantly better than turbofan engines where these accessory drives are generally charged against the engine. The relatively low time per flight compared to turbofan airplanes indicates significantly higher demands on starter drives, more frequent high electrical and hydraulic demands and more operation at high TIT per flight hour. These considerations have an impact. If the premature removal rates are keyed to the number of flights, the premature removal rate for the turboprop including the propellor is approximately half of that of the turbofan.

Mission aborts for the turboprops, including the propellor, are about three to five times as high as the turbofan per flight hour but are more comparable on the basis of the number of flights. Approximately 40% of the turboprop aborts are due to the propellor system. The aborts due to the gearbox are not sufficiently documented; however, they appear to be of relatively low incidence.

It is concluded that on the basis of flying the same mission, the turboprop power unit including the propellor would be approximately equivalent to the turbofan engine so far as maintainability, reliability and maintenance costs are concerned. The propellor appears to have a much greater impact on both reliability and cost than does the gearbox and that a 50% improvement in the propellor could make the turboprop measurably superior to the turbofan in the overall record.

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